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WATER AND LIFE.

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[*Read November 12, 1913.*]

It was assuredly not chance that led Thales to found philosophy and science with the assertion that water is the origin of all things. Whether his belief was most influenced by the wetness of animal tissues and fluids, or by early poetic cosmogonies, or by the ever-present importance of the sea to the Ionians, however vague his conception of water may, indeed must, have been, he at least expressed a conclusion which proceeded from experience and serious reflection. Later, when positive knowledge had already grown to be a substantial basis for speculation, both meteorological and chemical views contributed to Aristotle's decision to include water among his elements. And it is especially worthy of note that of earth, air, fire, and water, the last is the only one which happens to be an individual chemical compound. From that day to this the unique position of water has never been shaken. It remains the most familiar and the most important of all things.

Within a comparatively recent time, to be sure, it has definitely lost its claims as a true element, in the modern sense, but meanwhile almost every great development of science has but contributed to make its importance more clear. In physics, in chemistry, in geology, in meteorology, and in biology nothing else

threatens its preëminence. The physicist has perforce chosen it to define his standards of density, of heat capacity, etc., and as a means to obtain fixed points in thermometry. The chemist has often been almost exclusively concerned with reactions which take place in aqueous solution, and the unique chemical properties of water are of fundamental significance in most of the departments of his science. In geology Neptunism has at length won a certain though incomplete triumph over Plutonism, and the action of water now appears to be far the most momentous factor in geological evolution. The meteorologist perceives that the incomparable mobility of water, which depends upon its peculiar physical properties and upon its existence in vast quantities in all three states of solid, liquid, and gas, is the chief factor among the properties of matter to determine the nature of the phenomena which he studies; and the physiologist has found that water is invariably the principal constituent of active living organisms. Water is ingested in greater amounts than all other substances combined, and it is no less the chief excretion. It is the vehicle of the principal foods and excretory products, for most of these are dissolved as they enter or leave the body. Indeed, as clearer ideas of the physico-chemical organization of protoplasm have developed, it has become evident that the organism itself is essentially an aqueous solution in which are spread out colloidal substances of vast complexity. As a result of these conditions, there is hardly a physiological process in which water is not of fundamental importance.

All of these circumstances, which completely justify the interest in water which Thales and Aristotle, and nearly all later students of nature have manifested, depend in great part upon the quantity of water which is present outside the earth's crust, and upon its often unique physical and chemical properties. Doubtless if it were not for the enormous quantity of water which exists upon our planet, all its physical properties would be of little avail to bring about its universal importance in nature.

Of the total extent of the earth's surface, the oceans make up about three fourths, and they contain an amount of water sufficient if the earth were a perfect sphere to cover the whole area to a depth of between two and three miles. This corresponds to about 0.2

per cent. of the volume of the globe. The occurrence of water is moreover not less important and hardly less general upon the land. In addition to lakes and streams, water is almost everywhere present in large quantities in the soil, retained there mainly by capillary action, and often at greater depths. The atmosphere also contains an abundance of water as aqueous vapor and as clouds. Now the very occurrence of water upon the earth and especially its permanent presence is due in no small degree to its chemical stability in the existing physical and chemical conditions. This stability is of great moment in the various inorganic and organic processes in which water plays so large a part. In the first place, the chemical reactions in which it is concerned during the process of geological evolution, though they are no doubt in the total of great magnitudes, are both slow and far from violent. Long since any very active changes of this sort, so far as the superficial part of the crust is concerned, have run their course. In the second place, water is really, at the temperature of the earth, and in comparison with most other chemical substances, an extremely inert body, for the union of hydrogen with oxygen is so firm that it is not readily dissolved.

Thus water exists as a singularly inert constituent of the atmosphere, as a liquid nearly inactive in chemical processes on the surface and in the soil, and everywhere as a mild solvent which does not easily attack the substances which in great variety dissolve in it. The chemical changes which do follow upon solution are not such as to produce substantial chemical transformations, and most substances can pass through water unscathed. The nature of water, then, is a great factor in the chemical stability which no less than the physical stability of the environment is essential to the living mechanism.

Thermal Properties.

These characteristics were recognized at an early stage in the development of modern science, and in many cases their special importance in meteorology and in other departments of the sciences of nature is almost self-evident.

Specific Heat.

First among these is the heat capacity, or as it is more commonly termed, the specific heat of water. This quantity has the value of 1.000 for the interval between 0° and 1° cent., a number which is due to the choice of water in defining the calorie or fundamental unit of heat.

It is unnecessary to enter upon an elaborate analysis of the data concerning specific heats, for the magnitude of the specific heat of a substance is dependent upon its chemical nature, as was first made clear by Dulong and Petit in 1819. The law which bears their name consists of the statement that in the case of elementary substances the product of specific heat and atomic weight is a constant, — roughly, 6.4. Certainly this so-called law is a mere approximation, and some elements, notably carbon, silicon, and boron, at the ordinary temperature depart widely from its requirements, but in the main the approximation holds good. Later the researches of Neumann, Garnier, Cannizaro, and especially of Kopp, made possible an extension of the law to compounds.

It is evident that the law of Dulong and Petit amounts to the statement that for all elementary substances the quantity of heat which is required to change the temperature of every atom, regardless of its nature, is a constant. So it is that the conclusion is warranted that water shares the characteristic of very high specific heat with a very small number of substances, among which hydrogen and ammonia are probably the only important chemical individuals. From this conclusion another follows directly, namely, that water possesses certain nearly unique qualifications which are largely responsible for making the earth habitable or at least very favorable as a habitation for living organisms. It need hardly be pointed out that this importance of the high heat capacity of water is a very well-known fact. Even in the early decades of the nineteenth century, when natural theology and arguments from design were the subject of lively controversy, especially in England, such subjects were very familiar, and an excellent temperate discussion from the theologian's side will be found in Whewell's Bridgewater Treatise. At that time, before a

clear formulation of the concept of adaptation existed, it was of course impossible to disentangle such natural fitness from the results of the organic evolutionary process. In the more modern period since the publication of "The Origin of Species," the late Prof. J. P. Cooke of Harvard has dwelt upon this and other properties of water. He too endeavored to employ such facts as theological arguments, but in spite of many sound contentions with less success in a more skeptical age.

The most obvious effect of the high specific heat of water is the tendency of the ocean and of all lakes and streams to maintain a nearly constant temperature. This phenomenon is of course not due alone to the high specific heat of water, being also dependent upon evaporation, freezing, and a variety of circumstances which automatically mix and stir water. But in the long run the effect of high specific heat is of primary importance.

A second effect of the high specific heat of water is the moderation of both summer and winter temperatures of the earth. It is not easy to estimate the total magnitude of this effect, but the manner in which it comes about is well illustrated by the differences between seaboard and inland climates or between the climate of a large part of the United States, which is a continental climate, and that of Western Europe, which is essentially an insular climate. In the most extreme form such moderation of climate is to be observed on the high seas and upon small islands. There are found the smallest known differences between the mean temperature of different months of the year and of different hours of the day and the least tendency to violent changes of temperature. The calculation of Zenker regarding normal temperatures may be cited as a good illustration of the nature of the case. (See page 6.)

The high heat capacity of water operates in still another manner to regulate temperature upon the land and at the same time to increase the mobility of the environment of marine organisms. For directly or indirectly it is involved in the formation and duration of ocean currents, especially the movement of water in the depths from the polar to the tropical seas, and it determines the amount of heat carried by such currents. A similar and even more important "function" is the direct promotion of winds,

with the resulting distribution of aqueous vapor throughout the atmosphere, a primary factor in the dissemination of water by means of the rainfall. Here the essential thing is the existence of a warm reservoir in the tropics and of two similar cold reservoirs at the poles. Under these circumstances the circulation of winds, bearing away water vapor from the tropical oceans, is inevitable, and the process is intensified by the high specific heat of water.

NORMAL TEMPERATURES. CENT.

Latitude.	Continental Climate.	Marine Climate.	Difference
0°	34.6	26.1	−8.5
10	33.5	25.3	−8.2
20	30.0	22.7	−7.3
30	24.1	18.8	−5.3
40	15.7	13.4	−2.3
50	5.0	7.1	2.1
60	−7.7	0.3	8.0
70	−19.0	−5.2	13.8
80	−24.9	−9.2	16.7
90	−26.1	−8.7	17.4

The living organism itself is directly favored by this same property of its principal constituent, because a given quantity of heat produces as little change as possible in the temperature of its body. Man is an excellent case in point. An adult weighing 75 kg. (165 lb.) when at rest produces daily about 2 400 great calories, which is an amount of heat actually sufficient to raise the temperature of his body more than 32 degrees cent. But if the heat capacity of his body corresponded to that of most substances, the same quantity of heat would be sufficient to raise his temperature between 100 degrees and 150 degrees. In these conditions the elimination of heat would become a matter of far greater difficulty, and the accurate regulation of the temperature of the interior portion of his body, especially during periods of great muscular activity, well-nigh impossible. Extreme constancy of the body temperature is of course a matter of vital importance,

at least for all highly organized beings, and it is hardly conceivable that it should be otherwise. In the first place, marked influence of change of temperature upon chemical reaction is almost universal, and as a rule an increase of 10 degrees cent. in temperature will more than double the rate of a chemical change. Secondly, all living organisms contain both chemical substances and physico-chemical structures or systems which begin to be altered and usually irreversibly altered, at a temperature which is very little above that of the human body. It is perhaps imaginable that conditions might be otherwise in beings of a very different kind, but to-day every chemist well knows that if he is to control a chemical process, almost the first desideratum is rigid regulation of the temperature at which the process takes place.

It is therefore incontestable that the unusually high specific heat of water tends automatically and in most marked degree to regulate the temperature of the whole environment, of both air and water, land and sea, and that of the living organism itself. Likewise the same property favors the circulation of water by facilitating the production of winds, beside contributing to the formation of ocean currents. Here is a striking instance of natural fitness which in like degree is unattainable with any other substance except ammonia.

Latent Heat.

Very different from specific heat in their relationship to the chemical constitution of a substance, but not unlike it in biological importance, are the so-called latent heats of melting and of evaporation. The latent heat of melting is expressed as the number of calories which are required to convert one gram of solid at the freezing point into one gram of liquid at the same temperature. For water its value is approximately 80, which indicates that the same quantity of heat must be employed to melt ice as to raise the temperature of the resulting ice-water to 80 degrees cent.

The latent heat of evaporation is similarly defined as the number of calories required to change one gram of liquid into vapor. Its magnitude depends upon the temperature at which the process

takes place. The latent heat of evaporation of water is approximately 536. There is required, accordingly, as much heat to boil away one gram of water as to raise the temperature of 536 grams through 1 degree cent.

There are a number of important effects of the high latent heats of fusion and evaporation of water upon the meteorological processes. When, for example, a body of water becomes cooled to its freezing point, the further abstraction of heat cannot lower its temperature below that point, which to be sure is somewhat variable in the case of salt water. And so long as water and ice exist in contact, the system constitutes a thermostat, a very accurate one if the water be fresh, which changes only in respect to the quantities of ice and water as heat is added or removed. Heating serves merely to melt the ice, cooling to freeze the water. Accordingly as long as the earth shall remain habitable, the cooling of its oceans and seas will remain rigidly limited by their freezing point. However inclement the atmosphere, the ocean can always support life until the final extinction of water by cold.

It is worthy of note that the freezing point of water, though to man with his carefully regulated body-temperature apparently low, is in reality very high indeed compared with that of any like substances, — perhaps 100 degrees cent. above the average.

TABLE OF MELTING POINTS.

		Degrees Cent.
Water	H_2O	0.0
Hydride of antimony	SbH_3	−91.5
Hydride of arsenic	AsH_3	−113.5
Hydrobromic acid	HBr	−87
Hydrochloric acid	HCl	−112.5
Hydrofluoric acid	HF	−92.3
Hydriodic acid	HI	−50
Methane	CH_4	−185.8
Carbon dioxide	CO_2	−57
Hydride of phosphorus	PH_3	−132.5
Hydrogen sulphide	H_2S	−85.6
Sulphurous oxide	SO_2	−76
Ammonia	NH_3	−75
Nitric oxide	NO	−167

This is, no doubt, one of the most important facts with which we are concerned, for while a very large number of chemical processes take place quite freely at 0° the conditions are very different at the freezing point of ammonia for instance. At that temperature the velocity of most chemical processes is but a fraction of one per cent. of their velocity at 0°, and a large part of the chemical activity which is familiar to us ceases.

The result of the unusually high freezing point of water and of the phenomena of latent heat is felt, however, not merely in the avoidance of an excessive fall in the temperature of lakes and seas. As above explained, whenever the ocean comes in contact with climates of very low temperature it tends to moderate them, the more effectively the greater the disparity between the temperature of the air and that of the water, and here latent heat is quite as important a factor, though indirectly, as specific heat.

It remains to point out that the latent heat of melting of water is nearly the greatest which has yet been discovered, being exceeded in fact by that of ammonia alone.

Accordingly, the processes above described possess nearly the highest possible efficiency. A very large amount of heat must be abstracted from a body of water before it can be solidified; after a given amount of cooling a very large quantity of water must remain liquid; a body of water at 0° cent. can warm up a very large amount of colder air with the formation of a very small quantity of ice. Thus the permanency of the ocean, and the moderating effect of water upon cold climates are very nearly maximal. These are also facts, directly dependent upon the physico-chemical nature of water, which are remarkably favorable to the organism.

Still more important is the latent heat of evaporation of water. Wherever water is in contact with the air, evaporation must take place, until, if the system be of small dimensions, equilibrium is established between aqueous vapor and the liquid, in short, until the air is saturated with water. Unlike freezing, which occurs only at one particular temperature, this process goes on continuously throughout all ranges of temperature at which liquid water can exist, and even upon ice at low temperatures. It is always accompanied by the conversion of heat in the amount measured

by the latent heat of evaporation into other forms of energy; the heat becomes latent. Since air in contact with water is rarely saturated with aqueous vapor, owing to the constant movement of the atmosphere, the process of evaporation, with the accompanying conversion of heat into latent heat, is a continuous process. The phenomenon is a variable one, however, for while at high temperature, both because of the greater supply of heat and because of the greater amount of water vapor that the air can hold, the process is very important and active, at low temperature it is far less considerable. This in itself is no doubt a benefit, because it tends especially to restrict the upward march of temperature when the temperature is high, but it is of minor importance when the temperature is low.

In view of the other favorable qualities of water it is perhaps not surprising to find that its latent heat of evaporation is by far the highest known. So great in truth is this quantity and so important the process that the latent heat of evaporation is one of the most important regulatory factors at present known to meteorologists.

When the sun shines upon a body of water, only a small part of the energy which the water receives contributes to the elevation of its temperature. Thus FitzGerald has concluded, from his studies of Lough Derg in Ireland during clear hot summer weather, that in the morning the surface temperature rises about 0.6 degrees per hour This, however, appears to account for but a small fraction of the solar heat which the lake had taken up; the rest must have been expended in evaporation. Another element of great importance is the transparency of water. As a result, the rays of the sun are not absorbed by the mere surface alone, but a considerable layer of water near the surface receives the heat.

At the equator the evaporation of the ocean appears to be about 2.3 meters per year, which involves more than 1 000 000 000 000-000 calories of latent heat per square kilometer. The amount of heat which is employed in evaporating water from one hundred square kilometers of the tropical ocean is accordingly vastly more than all the energy employed in the metabolism of the total population of the United States, and it amounts to more than 100-000 000 horse-power. This is equivalent to more than one

horse-power per square meter day and night throughout the year. To a greater or less extent all over the earth this same process goes on, and as a result the water vapor in the air probably averages between 15 and 20 kg. per square meter of the earth's surface, an ample supply for the formation of rain. The effect of this enormous evaporation to moderate the temperature of the tropics is very considerable; but the heat which thus disappears is not lost. Rendered latent at the place of evaporation, it is turned back into actual heat at the point of condensation, and thus serves to warm another, and cooler locality.

This process, so vast that all the water-power of the globe may be regarded as its secondary by-product, possesses in respect to its tendency to moderate and equalize the temperature of ocean, of lakes, and of the climates of all the earth, a maximal value. No other liquid could during the evaporation of a given quantity of material bind so much heat; no other vapor could yield so much heat upon condensation.

Quite as important to man as this great power of meteorological regulation is the corresponding physiological activity, evaporation of water from the skin and lungs. In an animal like man whose metabolism is very intense, heat is a most prominent excretory product, which has constantly to be eliminated in great amounts, and to this end only three important means are available,— conduction, radiation, and the evaporation of water. The relative usefulness of these three methods varies with the temperature of the environment. At a low temperature there is little evaporation of water, but at body temperature or above there can be no loss of heat at all by conduction and radiation and the whole burden is therefore thrown upon evaporation. The manner in which evaporation becomes important in temperature regulation is well illustrated by the following calculation from a chart of Rubner's. The experiments upon which the chart is based were made upon the dog, an animal which lacks man's apparatus of sweat glands. The values of the table on page 12 are only approximate.

In plants evaporation is even more important than in animals. Evidently such adaptation of the physiological processes to the conditions of the environment is enormously favored by the high latent heat of evaporation.

Temperature. Degrees.	Heat Loss by Evaporation, Per Cent.
9	16
11	19
13	22
15	25
17	27
19	30
21	32
23	32
27	36
29	42
31	58
33	64
35	79

There is still another beneficial result of this property; the great variation in the vapor tension of water which accompanies variation in temperature. Vapor tension measures the amount of vapor which is present in the atmosphere when it is in contact with a liquid and after it has become saturated with the liquid's vapor. Now, according to a well-known law the rate of increase of vapor tension, or in other words the amount of vapor which the air can hold, is greater the greater the latent heat of vaporization. Hence degree by degree there is more variation in the vapor tension of water than there could be if the latent heat were lower. Such great variability in the quantity of water which the air can hold is in meteorology the most important characteristic of aqueous vapor. The relationship between vapor tension and temperature (centigrade) is shown in the accompanying table.

Temperature. Degrees.	Vapor Tension. Millimeters.
0	4.60
10	9.16
20	17.39
30	31.55
40	54.91
50	91.98
84	417.0
92	611.0
100	760.0

These variations are what make possible both the evaporation of water and its precipitation as rain and as dew in the meteorological cycle. And therefore the high latent heat of vaporization of water is in still another manner a most favorable circumstance in its effect upon the organisms.

To sum up, this property appears to possess a threefold importance. First, it operates powerfully to equalize and to moderate the temperature of the earth; secondly, it makes possible very effective regulation of the temperature of the living organism; and, thirdly, it favors the meteorological cycle. All of these effects are true maxima, for no other substance can in this respect compare with water.

Thermal Conductivity.

The heat conduction of water is also a maximum among ordinary liquids, and though very low compared with good conductors like metals, must favor the equalization of temperature within the living cells whose structure hinders the establishment of convection currents.

Expansion before Freezing.

A final thermal property of water remains to be considered, namely, its anomalous expansion when cooled at temperatures near the freezing point.

This unique property of water is the most familiar instance of striking natural fitness of the environment, although its importance has perhaps been overestimated. If, however, water like all other common substances, steadily contracted on cooling so that its point of maximum density fell at the freezing point, it is impossible to say how great would be the disadvantage for living organisms. Certain it is that life upon the earth would be thereby very greatly restricted. For this property, together with the by no means unique phenomenon of expansion upon solidification, is very largely responsible for the permanence in liquid state of many bodies of water in cold climates. In salt water the anomalous contraction disappears, and the lack of paleocrystic

ice is due to the density of ice and to the great mass of the ocean and the movement of its waters.

There is an old experiment of Rumford's which well illustrates what conditions must have been had the contraction of water been normal and ice denser than water. He found that in a vessel filled with water, which contains ice confined at the bottom, it is possible to heat and even boil the superficial portion of the water without melting the ice. And so it would be with lakes, streams, and oceans were it not for the anomaly and the buoyancy of ice. The coldest water would continually sink to the bottom and there freeze. The ice once formed could not be melted, because the water would stay at the surface. Year after year the ice would increase in winter and persist through the summer, until eventually all or much of the body of water, according to the locality, would be turned to ice. As it is, the temperature of the bottom of a body of fresh water cannot be below the point of maximum density; on cooling further the water rises; and ice forms only on the surface. In this way the liquid water below is effectually protected from further cooling and the body of water persists. In the spring the first warm weather melts the ice, and at the earliest possible moment all ice vanishes.

Such are the important thermal properties of water, and in briefest outline their unique fitness for the living mechanism. No other known substance could be substituted for water as the material out of which oceans, lakes, and rivers are formed, and as the substance which passes through the meteorological cycle without radical sacrifice of some of the most vital features of existing conditions. Ammonia in these respects is the only substance now known which approaches the fitness of water. But not only is it almost inconceivable that ammonia should ever occur in sufficiently vast quantities upon a planet's surface, but it is evident as well that ammonia wholly lacks the qualification of anomalous expansion, and also in some of the most important of the other thermal properties falls far short of water; while in latent heat of melting and in specific heat its advantage over water is inconsiderable.

It is obvious that upon a body like the earth the state of the oceans, and the meteorological phenomena, are of the utmost

importance to all living things. Unless these be favorable, human experience and reflection alike agree that life could not widely exist. It seems therefore almost safe to say, on the basis of its thermal properties alone, that water is the one fit substance for its place in the process of universal evolution, when we regard that process biocentrically.

The Action of Water upon Other Substances.

Although the thermal properties of water make up the classical subject matter for discussions of the fitness of the natural environment, other no less important physical properties exist. Such especially are those characteristics of liquid water which in no small measure determine the nature of the resulting physico-chemical systems when other substances, whether soluble or insoluble, crystalline or colloidal, are brought into contact with it: I mean the solvent power, the dielectric constant, together with the related ionizing power and the surface tension.

Water as a Solvent.

As a solvent there is literally nothing to compare with water. In truth its qualifications are on this point so uniq e and obvious that nobody seems to have taken the trouble to gather together the evidence, and accordingly, beyond the bare assertion, a brief statement of the facts is not easy. In the first place, the solubility in water of acids, bases, and salts, and most familiar classes of inorganic substances is almost universal.

Relatively few of these bodies are highly insoluble, very many are exceedingly soluble in water. Apart from their electrolytic dissociation and hydrolysis, which will be later discussed, the chemical changes wrought upon such dissolved substances in solution are commonly very unimportant. For chemical inertness, depending upon great stability, is a most significant characteristic of water, and undoubtedly a highly advantageous one as well. On the whole the best evidence for the efficiency of water as a solvent of inorganic substances is to be found in the data of geology. Of all geological agents water appears to have been by far the most active within the periods of which investigation is

made possible by the geological record. Rainfall, the movement of surface streams and of water beneath the ground, and wave action, all contribute to the work of disintegration, sedimentation, etc., partly by dissolution of soluble material, partly by mechanical action. But mechanical action is itself much increased by the loosening which earlier dissolution has caused. In this manner the great solvent power of water throughout its meteorological cycle largely contributes to the mobilization of many materials which could not otherwise be brought to the organisms which need them.

It has been calculated by Murray that the total yearly run-off of all the rivers of the earth is about 6 500 cubic miles, carrying nearly 5 000 000 000 tons of dissolved mineral matter and prodigious quantities of sediment. The average composition of such water has been estimated as follows:

		Parts per Million.
Potassium as	K_2O	2.40
Sodium as	Na_2O	7.10
Lithium as	Li_2O	0.20
Calcium as	CaO	43.20
Magnesium as	MgO	14.70
Manganese as	Mn_3O_4	1.20
Iron as	FeO	2.80
Aluminum as	Al_2O_3	3.10
Silicon as	SiO_2	16.40
Carbonic acid	CO_2	46.00
Phosphorus as	P_2O_5	0.30
Nitric acid as	N_2O_5	3.80
Sulphuric acid	SO_3	8.00
Chlorine	Cl	3.70
Ammonia	NH_3	0.07
Total mineral matter,		152.97

It is of course almost exclusively to these constant accessions that the ocean owes its salinity, which in the course of time has reached well-nigh inconceivable magnitude. The common salt alone in the oceans of all the earth amounts to not less than 35 000 000 000 000 000 tons. Not less significant of the solvent

power of water is the variety of elements whose presence in sea water can be demonstrated, thus proving that the total store of them is in any case enormous. They include hydrogen, oxygen, nitrogen, carbon, chlorine, sodium, magnesium, sulphur, phosphorus, which are easily demonstrated; further, arsenic, caesium, gold, lithium, rubidium, barium, lead, boron, fluorine, iron, iodine, bromine, potassium, cobalt, copper, manganese, nickel, silver, silicon, zinc, aluminum, calcium, and strontium.

Equally striking is the evidence in regard to the first stages of this geological process. Under the action of water, aided to be sure in many cases by dissolved carbonic acid, every species of rock suffers slow destruction. All substances yield *in situ* to the solvent work of water, and the dissolved parts may all be found in the great final reservoir, the ocean. It has been proved that nearly every one of the substances which are thus set in motion upon the face of the earth are placed under contribution by life, for biochemical analysis reveals them as constituents of living organisms, absorbed either on their way down from the mountain tops to the ocean, or by the marine flora and fauna.

Not less valuable to the community of living things than the dissolution of the rocks is the disintegration and transport of solid material, largely dependent thereon, which among its many results includes the preliminary steps of soil formation. By these familiar and enduring geological means chemical substances are mobilized in the greatest variety of forms and conditions and thus rendered available for the living organism. It is clearly evident from the chemist's long experience with solvents that no other fluid could permanently carry on this process with such acceptable regularity and efficiency. For no other chemically inert solvent can compare with water in the number of things which it can dissolve, nor in the amounts of them which it can hold in solution; and of course any chemically active solvent must sooner or later exhaust itself by its chemical action, when the cycle must cease. Here then is a fitness of water which is open to doubt.

Let us turn for further proof to the organism itself, taking blood serum as a source of information. The composition of this substance (in the case of the cow) is roughly as follows:

	Parts per 1 000.
Water	913.6
Protein	72.5
Sugar	1.05
Cholesterine	1.24
Lecithine	1.68
Fat	0.93
Organic phosphoric acid	0.01
Na_2O	4.31
K_2O	0.26
CaO	0.12
MgO	0.45
Cl	3.69
P_2O_5	0.08

Most of these substances are in solution, and unquestionably a host of others are present with them, in small and varying amounts. Among these may be mentioned, iodine, bromine, iron, sulphates, urea, ammonia, benzoic acid, amino-acids, etc. But indeed all substances found in urine (see below) also occur in blood. It cannot be doubted that if the vehicle of the blood were other than water the dissolved substances would be greatly restricted in variety and in quantity, nor that such restriction must needs be accompanied by a corresponding restriction of the life processes.

The composition of the urine provides another excellent illustration of the utility of the solvent power of water. In the course of its complex chemical processes a higher organism produces a host of end-products which must be removed, and also finds itself accidentally in possession of a great variety of other useless substances which require excretion. The solvent power of water is one of the great factors in facilitating this task. Human urine has been reported to contain in solution the following substances: urea, carbamic acid, creatinine, creatine, uric acid, xanthine, guanine, hypoxanthine, adenine, paraxanthine, heteroxanthine, episarkine, epiguanine, oxalic acid, allantoine, hippuric acid, phenaceturic acid, benzoic acid, phenolsulphuric acid, skatoxylsulphuric acid, paraoxyphenylacetic acid, homogentisic acid, urobiline, urochrome, uroerythine, glucose, levulose, lactose, numerous compounds of glycuronic acid, glycine, alanine, leucine, tyrosine, and other amino-acids, various enzymes, putrescine,

cadaverine, and countless other organic substances, chlorides, bromides and iodides, phosphates and sulphates, potassium, sodium, ammonia, calcium, magnesium, iron, carbonic acid, nitrogen, argon, etc.

Here again it is sure that such variety could not be attained with another solvent. It is no exaggeration to say that except atmospheric oxygen and carbonic acid, nearly all the food of living organisms is water borne, and all material in its passage into the body, through the body, and out of the body nearly always employs the same vehicle. Certainly no other form of transport would be so efficient and so economical.

Ionization.

If therefore aqueous solutions are, apparently of necessity, the very basis of the life processes, the state of substances when in this condition, and also when in contact with water, is of vital importance. Here two properties of water, the dielectric constant and the surface tension, exert a cardinal influence.

Among the phenomena of solution those which are related to electrolytic dissociation, as suggested by the hypothesis of Arrhenius, have deservedly received a great deal of attention since the secure establishment of the new science of physical chemistry, in the eighties of the last century. In the course of time the belief that in aqueous solution the molecules of all acids, bases, and salts are more or less split into particles which bear electrical charges has been universally accepted. These so-called ions are the source of nearly all the electrical phenomena of solution, whether in batteries, in the manifestations of animal electricity, or in simple conduction through an aqueous solution. But the more familiar electro-chemical processes are by no means the only results of ionization. An infinite number of chemical interactions between dissociated bodies follow inevitably. These changes are not, to be sure, decisive and irreversible, but balanced actions which vastly increase the variety of substances that exist in water.

It is certain that the extent and variety of ionization in water far surpass what is possible in any other solvent. One reason for this is most simple. The ionizing substances are so very much more

often soluble in water than in any other solvent, and when soluble are in general so much more highly soluble, that the opportunity for ionization in water is quite unparalleled. Further, ionization in solution unquestionably depends upon the dielectric constant of the solvent, in accordance with the principle first stated by Nernst that the greater the dielectric capacity of the solvent, the greater is the degree of electrolytic dissociation of substances dissolved in it, when the conditions are otherwise the same. This is the case because the tendency of the electrically charged ions to reunite and form electrically neutral molecules must be less the greater the dielectric constant of the solvent. Now the dielectric constant of water is nearly the highest at present known, and therefore ionization in water is on that account also more extensive than in almost any other solvent.

Finally for reasons that are not yet understood, the process of ionization in other solvents than water is a much more complex affair, and there can be no doubt that such complexity limits the phenomena which are dependent upon ionization.

Physiologically, as researches of the last twenty years clearly prove, the action of ions is of fundamental significance. The brilliant investigations of J. Loeb, and the long series of studies by various other physiologists of the influence of electrolytes upon colloids, form perhaps the most telling evidence for this belief. At all events, there is no question that the simple equilibria between acids and bases and salts are of extreme importance in the physiological processes. They lie at the very basis of the structure of all protoplasm, and the sure and definite relations between such bodies provide, as it were, a secure foundation for the more complex organic structures.

More obvious is the value of ions as sources of electricity. If the older electro-physiology of the third quarter of the nineteenth century has proved in some respects a sterile field, there can yet be no doubt that more subtly and quite apart from the nervous impulse and electrical fishes, electrical phenomena are everywhere involved in the most intimate of the physiological processes.

Even without further discussion of a subject that must soon lead into difficult and highly technical considerations, I feel sure that the existence of another important fitness of water is patent.

For ions are evidently a real contribution to the richness of the environment. They enhance the variety of chemical substances and of chemical reactions; they constitute a group of singularly mobile chemical agents; they provide electricity; and finally, aqueous solutions are by far the best source of ions.

Surface Tension.

Of all common liquids except mercury, water has the greatest surface tension. This fact is of enormous moment in biology, most obviously perhaps in its influence upon the soil. For surface tension and density determine the height to which a liquid will rise in a capillary system, and thus it comes about that the principal factor in bringing water within the reach of plants is the exceptional surface tension of water. The nature of the case is well explained by Hilgard:

"The liquid water held in the pores of the soil, in the form of surface films representing the curved surface seen in capillary tubes, and therefore tending to cause the water to move upwards, as well as in all other directions, until uniformity of tension is established, is of vastly higher importance to plant growth than hygroscopic moisture. It not only serves normally as the vehicle of all plant food absorbed during the growth of the usual crops, but also, as a rule, to sustain the enormous evaporation by which the plant maintains during the heat of the day a temperature sufficiently low to permit of the proper operation of the processes of assimilation and building of cell tissue."

The rise of water in capillary systems resembling soil, under the action of surface tension may be as much as ten feet. In soil itself the highest rise under the usual circumstances is unquestionably as much as four or five feet; but if the surface tension of water were like that of most liquids it could be, under similar conditions, but two or three feet. There seems to be little doubt that the rise of fluids in tall plants is also in large part due to the action of surface tension, and accordingly it must be much favored by the magnitude of that quantity in the case of water.

Finally, surface tension is of great importance; indeed, in simple

cases the one effective agent, in the phenomenon called adsorption.* On the basis of thermodynamical considerations first developed by Willard Gibbs, it is easy to show that whenever the dissolution of a substance changes the surface tension of a solvent, the distribution of the dissolved substance will not be strictly homogeneous. If the solution has a lower surface than the solvent, the surface of the solution will become more concentrated than the interior; or if the surface tension of the solution be greater than that of the solvent, the surface of the solution will become less concentrated than the interior. This result, quite insignificant in simple solutions, becomes a matter of much moment when, as in the case of suspensions of fine particles like animal charcoal, in emulsions, jellies, or any other system of like disperse heterogeneity of physical constitution, there occurs very great increase of surface area. Then it is that adsorption becomes a factor of the greatest weight; for, other things being equal, the total force of surface tension in a system is proportional to the area of surface. Under these circumstances dissolved substances are no longer distributed with any approach to equality or regularity in the system, but they collect at the surface in very great quantities, and in the most irregular manner.

Now, of all known physical structures there is none which rivals protoplasm in its fine complexity, and adsorption is therefore unquestionably a prominent agent in deciding its physico-chemical constitution. Moreover, adsorption influences and complicates almost every process of chemical physiology, for no product of life is without its colloids, i. e., substances which are finely divided and therefore endowed with great surface areas. The evidence of this universal importance of adsorption in biology is not to be briefly presented, but it may be found in almost endless profusion in such works as those of Freundlich and Bechhold.

It must not be supposed that the phenomena of adsorption in biology are simple and exactly understood. What is certain is that they are universal, and that surface tension lies at the root of the matter. This is because all living things are colloidal, and

* A familiar example of adsorption is the use of boneblack to decolorize syrup in the process of sugar refining. The colored matters are almost completely removed from solution, and cling to the surface of the charcoal.

I am inclined to think that most physiologists will admit that life without colloids is probably unthinkable, even in a world very differently constituted from our own. Colloidal structures are in fact the first and greatest factors in physical complexity of organization, and the principal force, unless it be in exceptional cases an electrical charge due to ions, which operates upon the colloidal structures, is surface tension. This then is another striking fitness of water above all other things.

Such are the facts which I have been able to discover regarding the fitness of water for the organism. The following properties appear to be extraordinarily, often uniquely, suited to a mechanism which must be complex, durable, and dependent upon a constant metabolism; heat capacity, heat conductivity, expansion on cooling near the freezing point, density of ice, heat of fusion, heat of vaporization, vapor tension, freezing point, solvent power, dielectric constant and ionizing power, and surface tension.

In no case do the advantages which these properties confer seem to be trivial; commonly they are of the greatest moment; and I cannot doubt, even after allowances have been made for the probability of occasional fallacies in the development of an argument which though simple is beset with many pitfalls, that they are decisive. Water of its very nature, as it occurs automatically in the process of cosmical evolution, is fit, with a fitness no less marvelous and varied than that fitness of the organism which has been won by the process of adaptation in the course of organic evolution.

If doubts remain, let a search be made for any other substance which, however slightly, can claim to rival water as the *milieu* of simple organisms, as the *milieu intérieur* of all living things, or in any other of the countless physiological functions which it performs either automatically or as a result of adaptation.

In truth, Darwinian fitness is a perfectly reciprocal relationship. In the world of modern science a fit organism inhabits a fit environment, whose primary constituent is water

DISCUSSION.

PROF. W. T. SEDGWICK.* *Mr. President and Fellow-Members:* It is, I think, now universally recognized that in order to have great poetry you must have a great subject. Comedy will always rank below tragedy, for this reason: Comedy deals with humor and with the lighter aspects of human life; tragedy deals with those darker, graver, and more solemn aspects with which humor has nothing to do. I think we are fortunate — those of us who are interested in water and water supplies — in being able, after hearing Professor Henderson's remarkable paper, to conclude that we have a great and worthy subject upon which to spend our lives. Water is an immense subject. It is more, — it is unique; and, as Professor Henderson has shown us, it would be impossible for us as living things to have the wonderful properties of life and yet to get along with water.

Professor Henderson began by speaking of Thales, who, as you remember, thought that all the stuff of the universe was fundamentally water. Now, Thales had traveled in Egypt and Babylonia, the two great centers of ancient civilization, and he had seen there in the Tigris and the Euphrates and in the Nile wonderful examples of rivers on the shores of which stood the most advanced civilizations of the time. The irrigation works in Babylonia, and also in Egypt, excited his astonishment. But what Thales didn't know was that in addition to the civilizations of the Nile and of the Euphrates were to come grander civilizations on the shores of the Mediterranean far surpassing those in importance, and leading on to the Europe and the America of to-day. Mankind has been associated with water and with great water courses and with great seas from the earliest times until now. Man has shunned, comparatively speaking, the high lands and the deserts, and has built his home beside the waters, beside great waters. We say that public opinion is the resultant of individual opinions blended together. We may say equally well that all these civilizations of ours are the resultant of life by great waters and life upon the products of great waters; and, as Professor Henderson has well said, we are ourselves largely made of water.

* Professor of Biology and Public Health, Massachusetts Institute of Technology.

This subject, it seems to me, is one that strangely opens the mind. I could not help thinking, as he was talking, of how Keats, the poet, chose for his epitaph: "Here lieth one whose name was writ in water." Poor Keats was defeated, — at the time at least he seemed defeated; he seemed a failure, he died early, probably of tuberculosis, and in despair chose as his epitaph, "Here lieth one whose name was writ in water." And yet, after hearing Professor Henderson, we cannot help feeling that no other monument could possibly be so good to write one's name upon for all eternity as a monument of water.

But, gentlemen, the important point, it seems to me, for us this afternoon is to felicitate ourselves upon the fact that once more — and this has happened many times — we have had at one of our meetings a man of high distinction, a man of science, who has brought us the latest results of his work, and enabled us to stand aside for a moment from the routine of professional life and look out upon our life work as something great and worthy. We have had in the past important papers from men like Professor Drown, who, alas, has gone; and from other great leaders in hydraulics and in chemistry and in biology. But I venture to say that we have never had a more fundamental and more far-reaching or a more important paper than that to which we have just listened; and I am very sure I express your gratitude, as I do my own, when I say this, and that Professor Henderson may take with him the assurance that every man of us has listened eagerly to what he has said. I have watched the faces of the audience as he was reading, and I feel sure that every one of us has got much from his paper. I hope that from time to time the Association may have papers of this kind, if it can get them, for certainly it is a fine thing thus to bring together men of the laboratory and men of the field. You could doubtless teach Professor Henderson a great deal about some aspects of water, and he has shown that he can teach us likewise.

PROF. DWIGHT PORTER.* One statement of Dr. Henderson's that was new to me was with reference to the constant increase in density of salt water in freezing. If I remember rightly, fresh water in the act of cooling from 39 to 32 and freezing becomes

* Professor of Hydraulic Engineering, Massachusetts Institute of Technology.

lighter and remains on the surface, and thereby protects the water underneath from freezing solid. I have been wondering what results from this principle as to the constant increase in density of salt water. Do bodies of salt water tend to freeze solid from top to bottom? If not, what prevents?

Professor Henderson. I am afraid I can scarcely answer that question adequately. Of couse it lies very far from my own field. I was quite as much surprised as anybody could be when I found out, in making a systematic survey of the properties of water, a couple of years ago, that the anomalous expansion did not apply to all waters. There is, of course, the phenomenon of anchor ice, so-called, and it is a fact that more often ice is found at the bottom of bodies of salt water than at the bottom of bodies of fresh water. But I think the only reason that salt water does not, now and then, freeze at the bottom and continuously up is that ice itself is so much lighter than water. That is a characteristic of ice that cannot be destroyed by the fact that it happens to be formed in salt water. And that is in itself a sufficient and curious comment upon the old teleological and natural theological speculations in connection with water. The old theologians, in picking out the anomalous expansion of water, picked out the one peculiarity of water that is of no particular importance to their cause, and threw away all the good ones, without exception.

SOME RECENT EXPERIENCES IN THE DEFERRIZATION AND DEMANGANIZATION OF WATER.

BY ROBERT SPURR WESTON, CONSULTING SANITARY ENGINEER.

[*Read February 11, 1914.*]

Since Salbach's discovery* in 1868, it has been known that certain ground waters could be freed from iron by aëration followed by filtration through gravel or sand; and since 1874, when the Charlottenburg works were completed, the introduction of this method has been rapid, especially in Germany, where such large cities as Berlin, Hamburg, Breslau, Dresden, Leipsic, Charlottenburg, Kiel, Brunswick, Hannover, and others are supplied in this way, some of them supplanting their filtered surface-water supplies because of the greater attractiveness and safety of the purified ground water.

In America the development has been slower. There are plants in successful operation at Far Rockaway, N. Y., and along the New Jersey coast; at West Superior, Wis.; Richmond, Mo.; Garretsville, Ohio; and in New England at Marblehead, Reading, Middleboro, and a few other places.

Because the original problem has been complicated in recent years, it will be well to review briefly the principles underlying the deferrization process.

PRINCIPLES OF DEFERRIZATION.

Iron exists in water as iron hydrate. This is soluble and unoxidized, and usually accompanied by mineral salts, carbon dioxide, or other gases, and perhaps by organic matter or manganese.

Iron can be precipitated from most ground waters — those low in manganese and vegetable-organic matter — by simple aëration by spraying, followed by filtration through sand or even fine gravel. Provided the water be properly treated beforehand,

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* "Berichte über die Erfahrungen bei Wasserwerken und Wasserversorgungen," Dresden, 1893.

the kind of filter, whether slow or rapid, whether filled with fine sand or coarse, has little to do with taking out the iron.

Simple aëration oxidizes the iron from the soluble unoxidized form to the insoluble oxidized form, from ferrous to ferric hydrate. It also effects the removal of some of the carbon dioxide. When one realizes that 1 part of oxygen per million will oxidize 7 parts of iron, it is easy to understand how an excess of oxygen may be obtained by a slight exposure to the air. The following table by Oesten* shows the degree of absorption of oxygen by water after being sprayed from various heights, at ordinary temperature and pressure.

TABLE I.

Height of Fall. Inches.	Oxygen Absorbed. Parts per Million.
4	4.42
10	5.00
20	5.75
40	9.73
80	10.57

If the absorption of oxygen and the oxidation of the iron were all, the problem would be easy. In many cases it is easy, and because of this fact many have been lead astray by the apparent simplicity of the process and have designed plants which have failed or have operated uneconomically.

Ferrous (iron) hydrate oxidizes quite readily to ferric hydrate; this latter is insoluble and in most cases coagulates and precipitates rapidly. Some waters, however, contain interfering substances which prevent the precipitation of the iron, holding it in the semi-soluble or colloidal form, and making its removal by filtration difficult. It is not the oxidation but the precipitation of the iron which is difficult to accomplish.

CAUSES OF INTERFERENCE.

It is to explain some of these causes of interference that this paper is written. Three of them are as follows: Carbon dioxide, organic matter, manganese.

* Schillings Jour. für Gas. und Wasserversorgung, *34*, 283.

Carbon Dioxide. All acids interfere with the precipitation of ferric hydrate, including the carbonic acid which has dissolved the iron from the soil; consequently it is necessary to so treat the water prior to filtration that not only will the iron be oxidized, but the carbon dioxide be eliminated as much as practicable. With waters of peculiar organic composition, especially those from beneath alluvial deposits or marshy areas, aëration can be carried so far as to make it impossible to coagulate the oxidized iron before filtration. These phenomena have been noticed at Reading, Mass.; Superior, Wis., and at other places.

Organic Matter. Not all organic matter interferes with the precipitation of iron. For example, the organic matter from deep wells in geologically old deposits not only does not interfere with the precipitation of iron, but assists in its removal; and in turn the iron causes the precipitation of the organic matter. They mutually precipitate one another.

However, other kinds of organic matter interfere seriously with the deferrization process, and the writer is of the opinion that the fresher and newer the organic matter, the more troublesome it is. Experiments have shown that extracts of freshly fallen leaves and grasses delay, while extracts of lignite and some peats assist, the deferrization process. They have also shown that all gelatinous bodies, like glue, gluten, and gums, interfere. These are much more apt to be present in actively decaying organic matter than in old deposits.

Certain kinds of organic matter, or, as the writer imagines, the new matter or that rich in humic acid, interfere with the coagulation of the iron when the water is excessively aërated. Lounsbury* found that at Superior, Wis., better results were obtained without the aërator than with it, because an excess of oxygen was already present in the water because of a leaky suction, and because the presence of carbon dioxide, which would be reduced from 12 to 4 parts per million by passing the water through the aërator, was necessary to prevent the soluble organic matter from interfering with the deferrization process; i. e., prevent the humic acid from combining with the iron.

Similar results were obtained at Reading, Mass., and the con-

* Trans. Am. Soc. C. E., 64, 182.

clusion that aëration can be too thorough was forced on the writer's unwilling mind. There the peculiar organic matter appeared in and disappeared from the water suddenly, and its effect was unmistakable. It was also learned at Reading that the iron could be induced to coagulate and the interference of organic matter avoided, by contact with broken stone, not by trickling the water over it, as in the rieseler of Piefke or in one of the many types of aërator, but by passing the water through submerged stones or coarse coke in a roughing filter.

Of course the same effect could be secured, but at a prohibitive cost, by storing the water for a very long period, but contact between the water and a rough surface like that provided by coke or broken stone, on which iron hydrate has accumulated, greatly accelerates the process, as shown by Clark.* The submergence of the filtering material prevents the loss of the CO_2 and the contact brings about the coagulation of the iron, notwithstanding the presence of a small amount of this interfering gas. In these cases, plants can be designed to remove part of the CO_2 by aëration and then bring about a precipitation of the iron by contact with submerged material.

Manganese. Until the Breslau calamity in 1906, when the manganese in the well supply rose suddenly to 220 parts per million, little attention was paid to manganese. Even water analysts paid little attention to it, and in this country its presence was ignored. It is true that a well water was condemned by Mr. Allen Hazen† in 1898 because of its high manganese, and Mrs. Ellen H. Richards reported that the deposits in the Brookline mains contained a high percentage of manganese. It has rarely, if ever, been reported in the published results of analyses by boards of health and water commissioners. Recently its presence at Reading and elsewhere, and the simplification of the methods for its determination, have caused it to be given proper attention.

Chemically, manganese is closely related to iron. It, however, reacts and precipitates more slowly, and it possesses the power of preventing the removal of the last traces of iron unless it itself be removed at the same time.

* Journal N. E. W. W. A., *11*, 277.
† Trans. Am. Soc. C. E., *64*, 174.

In a distribution system supplied with well water containing iron and manganese, deposits will be found nearest the wells which contain iron but little or no manganese, while those points farthest distant will be colored black with manganese.

At Hannover the writer was presented with three samples of precipitate as follows:

No. 298, from the distribution system before filters were introduced.

No. 299, from the filter material.

No. 300, from the water tower.

These samples were analyzed, the results being shown in the following table:

	Number.		
	298.	299.	300.
Iron (Fe)	57.89 per cent.	34.72 per cent.	14.27 per cent.
Manganese (Mn)	0.30 per cent.	1.24 per cent.	7.15 per cent.
Ratio (Mn : Fe)	1:193	1:28	1:3

For complete demanganization, it is necessary to increase the contact treatment beyond that necessary for deferrization alone.

EXPERIMENTS.

During 1913 the writer conducted three experiments for the Cohasset Water Company and the towns of Middleboro and Brookline, respectively.

The average analyses of the three waters are as shown by the table on page 32.

The remarkable fact about the above waters is the similarity of many of their characteristics; they have about the same turbidity, color, and free ammonia; they are all soft, contain little mineral matter, and their chlorine content is what one would expect from their location. They differ in the amounts of oxygen consumed, albuminoid ammonia, nitrates, iron, manganese, and carbon dioxide; it is these differences which are significant.

TABLE II.

(Parts per Million.)

Source of Sample.		Cohasset Well.	Brookline Wells.	Middleboro Well.
		Averages.		
Turbidity, silica standard		3	4	11
Color, platinum standard		44	29	41
Oxygen consumed		5.6	1.88	.65
Nitrogen as	Free Ammonia	.052	.061	.049
	Albuminoid ammonia, total	.097	.088	.046
	Nitrites	.000	.001	.001
	Nitrates	.04	.19	.42
Chlorine		14.3	8.5	6.6
Alkalinity		30	40.1	
Hardness by soap method		16	47.1	26.6
Iron (Fe)		.73	.60	1.49
Residue on evaporation, total		80	105	68
Manganese (Mn)		.23	.26	.75
Carbon dioxide (free and half bound)		49.82	31.8	45
Dissolved oxygen		1.58	1.32	3.02

COHASSET SUPPLY.

The most difficult water to treat is that from Cohasset. This water is from a well which is fed both in the natural way and by irrigating the ground in the vicinity with the highly colored Lily Pond water. The objectionable features are the high amounts of organic matter and carbon dioxide. The incomplete oxidation of the organic matter originally in the Lily Pond water is shown by the analytical results. Manganese is also present and of course interferes with the deferrization process.

Experiments.

The first set of experiments was conducted by the Norwood Engineering Company, with the assistance of Mr. A. L. Gammage, of the writer's office. The devices used consisted of an aërator of the spray type discharging over slats into a series of subsiding basins having a capacity equivalent to 3.5 hours' flow. The water from the last of these basins discharged into a small Wilson filter containing a depth of 2 ft. of sand, having an effective size of from .35 to .40 mm. and operating at a rate of 103 million gallons

per acre per diem. The aërator reduced the CO_2 from 30 to 16 parts per million.

Two experiments were first made, as follows:

Experiment I. Treatment by aëration and filtration without the addition of chemicals.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Average color	40	26	35
Average iron	0.65	0.40	38

Experiment II. Like I, with the addition of 1 gr. of sulphate of alumina and 1 gr. of soda per million.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	40	20	50
Iron	0.70	0.40	43
Alkalinity	—	22	—
Carbon dioxide	—	16	—

These tests were unsatisfactory, insufficient iron and color being removed. The doses of chemicals were changed with the following results.

Experiment III. Without aëration and with the addition of 2 gr. of sulphate of alumina and 0.5 gr. of soda per gallon.

Theoretical period of coagulation, fifty-eight minutes.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	10	67
Iron	0.60	0.25	58
Alkalinity	10	3	70
Carbon dioxide	30	23	23

As will be noted, these results are greatly superior to those obtained in Experiment II. Samples of raw water when allowed to stand over night deposited iron, but samples of filtered water did not, showing that the removal of color helps to prevent the iron from precipitating.

Experiment IV. Two additional layers of slats were added to the aërator, making three in all. The experiment was conducted with aëration and filtration alone, without the addition of chemicals.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	24	20
Iron	0.5	0.45	10
Alkalinity	8	8	0
Carbon dioxide	38	10	74

The better removal of carbon dioxide indicates the better aëration obtained with the new aërator; the degree of deferrization, however, is less.

Experiment V. Like IV, but with the addition of 0.5 part of bleaching powder per million and 1 gr. of sulphate of alumina per gallon.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	27	15	44
Iron	0.55	0.30	45
Alkalinity	10	4	60
Carbon dioxide	28	11	61

This experiment shows a great improvement over the previous one, and, furthermore, no iron deposited from the water when standing over night. The raw water precipitated readily after standing.

Experiment VI. Like IV, with the addition of 1.5 gr. of sulphate of alumina and 0.5 gr. of soda per gallon.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	3	90
Iron	0.55	0.40	27
Alkalinity	9	4	55
Carbon dioxide	30	11	66

It will be noted that the color was removed almost completely, but that the treatment was insufficient for the precipitation of the iron. The sample of filtered water, however, stood two days without precipitating iron or increasing in turbidity.

Experiment VII. The coagulating basin was increased by two thirds, or to about 1.5 hours' flow. No chemicals were added, but a 5-ft. layer of crushed stone was placed in the tank beneath the aërator. Part of this stone was submerged.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	25	17
Iron	0.6	0.55	8
Alkalinity	11	11	0
Carbon dioxide	39	8	79

Experiment VIII. Like VII, but with the addition of 1.5 gr. of sulphate of alumina and 0.5 gr. soda per gallon.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	4	87
Iron	1.05	0.50	52
Alkalinity	11	7	36
Carbon dioxide	39	13	67

There were eight parts of carbon dioxide per million in the water passing through the crushed stone in the aërator. In the water leaving the bottom slats there were twelve parts per million; in that leaving the crushed stone, five parts per million, and in that in the first barrel, only three parts per million, the addition of the sulphate of alumina again increasing the carbon dioxide to 23 parts per million.

Experiment IX. Like VIII, with the addition of three parts of bleaching powder per million.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	0	100
Iron	1.10	0.23	79
Alkalinity	12	8	33
Carbon dioxide	38	11	71

These results are satisfactory, although they might be obtained with less addition of chemicals, provided the apparatus was arranged differently.

Experiment X. Like VII, but with the addition of 0.5 part of bleaching powder per million, 1.5 gr. of sulphate of alumina and 1.0 gr. of soda per gallon.

Determination.	Parts per Million.		
	Raw.	Filtered.	Percentage Removed.
Color	30	6	80
Iron	1.15	0.40	70
Alkalinity	12	15	25
Carbon dioxide	37	7	81

Experiment XI. Like VII, but with the addition of 1.5 parts of bleaching powder per million.

Determination.	Parts per Million		
	Raw.	Filtered.	Percentage Removed.
Color	30	24	20
Iron	1.15	0.70	39
Alkalinity	12	12	12
Carbon dioxide	38	3	92

These results, which were obtained in December, 1912, showed that satisfactory results could be obtained by the addition of bleaching powder to care for the organic matter, and sulphate of alumina and soda; but with an expenditure for chemicals of about $3.50 per million gallons.

To determine the feasibility of deferrization without chemicals when using mechanical filters, further experiments were conducted between January 17 and March 24.

The apparatus was the same as used during the previous experiments, and arranged as follows:

1. A wooden tank 3 ft. square, filled to the depth of 5 ft. with coarse broken stone.

2. A sprinkler, made by punching one hundred holes, each $\frac{1}{16}$ of an inch in diameter, in the bottom of an ordinary metal pail. The bottom of the sprinkler was 15 in. above the surface of the stone in the tank (the so-called trickler or rieseler).

3. Five barrels arranged in series; these served as a subsiding basin.

4. A small mechanical filter.

The apparatus was so arranged that the water fell 15 in. from the bottom of the sprinkler to the surface of the stones, and then trickled over the latter until the water level in the tank was reached. This level was about 6 in. above the bottom of the tank, and therefore the stones were not submerged for a depth of 4.5 ft.

Quality of the Water. During the experiments, the amount of iron in the raw water has varied between 0.40 and 1.15 parts; the amount of carbon dioxide from 40 to 56 parts; the amount of dissolved oxygen from 1.03 to 7.1 parts; the amount of color

from 35 to 50 parts; and the amount of manganese from 0.15 to 0.40 parts per million.

Rate of Filtration. Water was supplied to the aërator at the rate of 7.8 gal. per minute. This was equivalent to a rate of 50 000 000 gal. per acre per diem through the rieseler. The mechanical filter operated at the rate of 100 000 000 gal. per acre per diem.

Conduct of the Experiments. The apparatus ran from January 17 to January 22, as described. After January 22 an aërator consisting of a tray containing a 6-in. layer of stones, 1 in. to 2.5 in. in diameter, the surface of which was 5 in. below the aërator, was added. The aërator was supported by three layers of slats, spaced half an inch apart.

After February 11, the rieseler was raised so as to operate without submergence of its lower portion, and the aërator was raised so as to discharge at a point of 2 ft. above the stones.

On March 7 the pipes connecting the barrels serving as a subsiding basin were cleaned out, in order that sufficient water might be supplied to the mechanical filter.

On March 13 the first two barrels of the subsiding basin were filled with coke. This was completely submerged in the water.

Results of Experiments. Table III gives a summary of the results of these experiments.

The results of analysis of samples collected on March 24 show that the devices then in use produced the following results:

Determination.	Well Water.	Rieseler Effluent.	Filter Effluent.
Color	50	40	35
Iron	0.90	0.35	0.28
Carbon dioxide	54	8.6	8.0
Dissolved oxygen	2.17	10.39	10.25

On the above date the rieseler was operated at the rate of 50 000 000, and the filter at 100 000 000 gal. per acre per diem.

Notes on the Experiments. It will be readily observed that the bulk of the work was done before filtration. The reason for this is that contact between the water and the rough surfaces of the

stones or coke effects the displacement of the carbon dioxide by oxygen; the oxidation of the iron and the manganese, and the removal of color. The filter acts simply as a strainer. At the beginning of the experiments, the stones were clean, but in less than a month they showed a red coating. This, on analysis, was found to be iron rust mixed with some organic matter. In other words, notwithstanding the fact that the season was most unfavorable, on account of low temperature, for the establishment of contact action, the stones had begun to remove both iron and organic matter to a satisfactory degree. Having demonstrated that the iron and color could be brought below a safe limit under the most unfavorable conditions, the experiments were stopped.

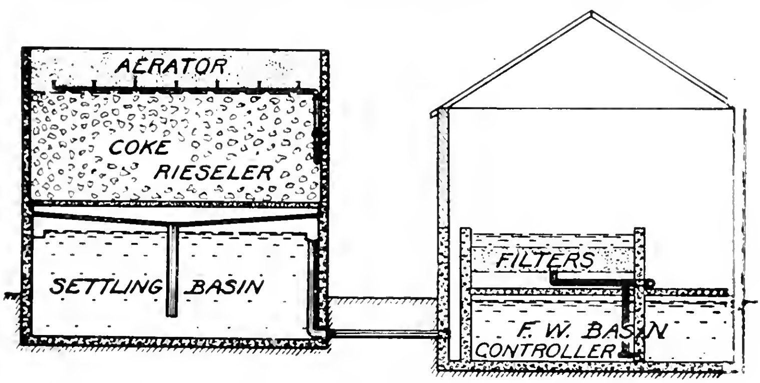


FIG. 1.
SKETCH SHOWING ARRANGEMENT OF COHASSET DEFERRIZATION PLANT.

Cohasset Deferrization Plant. Plans for a deferrization plant have been prepared by the Norwood Engineering Company and a contract has been let for their construction. The general arrangement of this plant is shown in Fig. 1. The plant consists of aërator and trickler supported above a small subsiding basin, the latter discharging into three mechanical filters of standard pattern, with filtered water basin beneath. The trickler is designed to operate at a rate of 75 million gallons per acre per diem, and is to be filled with coarse coke, 10 ft. deep. The piping is arranged so that the trickler may be operated submerged, partly submerged, or non-submerged. At certain times of year it will be impossible

TABLE III.

Cohasset Water Co. Deferrization Experiments.

(Parts per Million.)

Date, 1913.		1/22	1/28	2/5	2/14	2/18	2/28	3/7	3/13	3/18	3/24
Raw Water.	Color	40	42	45	35	45	50	50	50	50	50
	Iron	.55	.40	.40	.45	1.05	.80	.80	1.15	.95	.90
	Alkalinity	17	16	17	16		16				
	CO_2	40	38	53.7	56	53	45.5	52	53	53	54
	Dissolved oxygen			2.35	1.18	7.1	1.03	1.57	1.60	2.03	2.17
	Manganese				.40	.30	.25	.20	.15	.16	.16
Rieseler Effluent.	Color	38	35	40	45	40	35	45	45	40	40
	Iron	.38	.20	.25	.25	.40	.40	.54	.45	.60	.35
	Alkalinity	17	16								
	CO_2	22	18	30.3	29	11	3.25	9	8	9	8.6
	Dissolved oxygen			9.1	5.75	10.6	10.21	10.64	*a*10.68 *b*10.64	10.92 10.66	10.39 10.12
	Manganese				1.20	.30	.25	.20	.17	.16	.14
Filter Effluent.	Color	35	35	38	30	35	30	35	30	35	35
	Iron	.28	.10	.12	.11	.20	.30	.32	.30	.32	.28
	Alkalinity	16	16				16				
	CO_2	18	17	26.5	26	14	12	7.6	7.2	8.5	8.0
	Dissolved oxygen			12.83	7.37	10.1	10.17	10.57	10.67	10.74	10.25
	Manganese				.10	.25	.25	.20	.16	.14	.14

a = Rieseler in air. *b* = Rieseler submerged.

to aërate the water very much, and still remove the color and iron; nevertheless the period of contact may not be reduced. It is probable that the coke will have to be operated partly submerged.

BROOKLINE EXPERIMENTS.

The Cohasset water is difficult to purify because of humus matter and carbonic acid. The difficulty at Brookline is not so much the presence of specific interfering bodies, as at Cohasset, but the relatively small mass of iron to be precipitated. It is much easier, other things being equal, to precipitate five parts of iron per million than one, as may be shown by experiment.

Consequently the problem at Brookline is one of securing the economical degree of contact and the accumulation of a mass of iron hydrate on the surfaces of the material in the trickler.

Description of Experimental Devices. Four deferrization systems were tested at the Cow Bay pumping station by Superintendent F. F. Forbes and the writer. These may be described as follows:

System No. 1.

Aërator.

Coagulating basin having a capacity equivalent to 9.35 hours' flow.

Sand filter operating at a rate of 5 000 000 gal. per acre per diem, and containing a depth of 3 ft. of sand, the sand having an effective size of .41 mm.

System No. 2.

Aërator.

Coke trickler containing a depth of 2 ft. of coarse coke and operating at a rate of 75 000 000 gal. per acre per diem.

Coagulating basin having a capacity equivalent to one hour's flow.

Sand filter operating at a rate of 10 000 000 gal. per acre per diem and containing a depth of 30 in. of sand like that in Filter No. 1. The sand is supported on a layer of graded gravel one foot in depth.

System No. 3.

Like No. 2, but with a trickler having a depth of 5 ft. of coarse coke.

System No. 4.

Like No. 2, but with a trickler having a depth of 10 ft. of coarse coke.

All of the above systems were provided with suitable regulating devices or meters, and the various parts were large enough to permit safe conclusions to be drawn from the results of the experiments. For example, the tricklers were 3.0 and the filters 2.5 ft. in diameter.

It will be noted that the systems differ from each other chiefly in the character and degree of preliminary treatment before filtration; Filter No. 1, however, operated only one half as fast as Filters Nos. 2, 3, and 4.

The tricklers were put in service on August 1; the filters on August 6, and were operated as long as weather permitted.

Qualitative Results. The four systems were fairly efficient at the start, then the efficiency deteriorated slightly, and finally improved steadily until the end of the experiments. Over two hundred samples of water have been analyzed to determine the efficiencies of the four systems, but for the purpose of this paper the increase in the amount of dissolved oxygen, the decrease in the amount of carbon dioxide gas due to aëration, and the removal of iron will sufficiently illustrate the comparative qualitative efficiencies of the four systems.

The efficiency of the preliminary treatment is dependent largely upon the amount of dissolved oxygen added to the water and the amount of carbon dioxide removed, for the reason that the former assists and the latter retards the change of the iron from the soluble hydrate into the insoluble oxide of iron or rust. The removal of iron is the best index of the efficiency of the plant, and all of the many analyses which have been made show that the removal of manganese and turbidity is roughly proportional to the removal of iron. Filter No. 1, however, which operates at half the rate, removes color equally well with Filter No. 4.

TABLE IV.

Dissolved Oxygen and Carbon Dioxide.

(Parts per Million.)

Date.	Wells.		System No. 1.		System No. 2.		System No. 3.		System No. 4	
	Dissolved.		Dissolved.		Dissolved.		Dissolved.		Dissolved	
	O.	CO_2.	O.	CO_2.	O.	CO_2.	O.	CO_2.	O.	CO_2.
Aug. 7	1.52	18.0	7.52	21.0	7.62	15.0	9.83	12.0	10.00	8.2
Aug. 21	1.22	41.4	7.87	11.2	9.21	13.4	9.98	10.2	9.36	9.6
Sept. 4	1.25	22.6	6.87	8.3	8.19	6.5	10.57	7.6	9.20	5.8
Sept. 18	1.61	23.4	7.83	11.7	8.67	7.8	9.06	7.5	9.22	5.6
Oct. 2	2.02	24.8	8.01	9.0	8.55	5.9	9.15	5.5	9.30	4.2

The following tables show the results of preliminary treatment in the four systems with regard to the amount of dissolved oxygen, carbon dioxide, and iron.

TABLE V.

IRON.

(Parts per Million.)

Date.	Wells.	System No. 1.	System No. 2.	System No. 3.	System No. 4.
Aug. 7....	0.65	0.40	0.35	0.32	0.30
Aug. 14....	0.70	0.40	0.38	0.35	0.32
Aug. 21......	0.72	0.27	0.40	0.20	0.26
Aug. 28......	0.85	0.21	0.43	0.30	0.31
Sept. 4....	0.72	0.22	0.25	0.20	0.20
Sept. 11.....	0.85	0.30	0.35	0.20	0.25
Sept. 18.....	0.48	0.30	0.23	0.20	0.18
Oct. 2....	0.48	0.20	0.23	0.18	0.16
Oct. 15.........	0.68	0.20	0.23	0.20	0.16
Oct. 28.........	0.56	0.22	0.22	0.17	0.14
Nov. 15.........	—	—	—	—	0.12

In addition to the above, numerous other determinations have been made, but the ones given are typical.

The writer's opinion, based upon the above results, is that either System No. 3 or System No. 4, and probably System No. 1, would remove the iron from the water to a satisfactory degree. System No. 1, however, does not remove the carbon dioxide effectively, and the effluent from such a system in practice would have a greater corrosive action upon pipes than that from the other systems. A satisfactory plant in practice should reduce the iron to below 0.2 parts per million, and the carbon dioxide to at least 5.0 parts per million. System No. 2 does not satisfy these requirements. For the removal of iron only, systems Nos. 1, 3, and 4 would produce satisfactory effluents, and the comparative quality of the same would improve from No. 1 to No. 4. Apart from the corrosive action of the water, the relative merits of the three systems should be judged upon a cost basis.

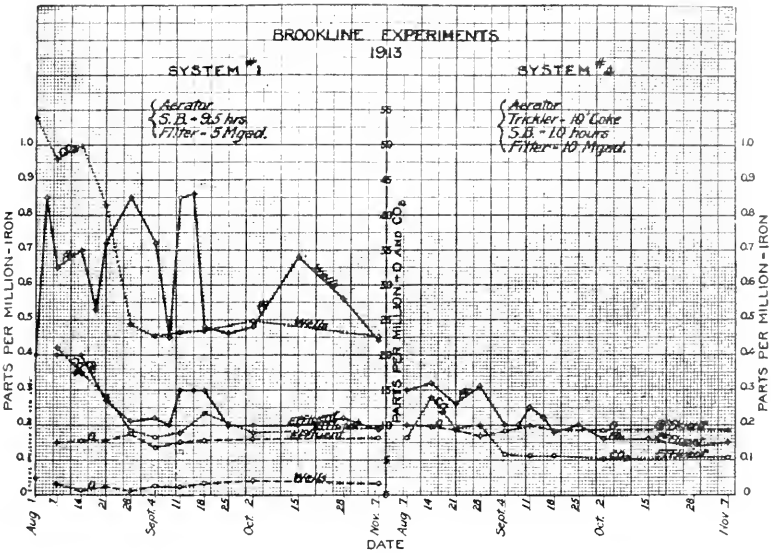


Fig. 2.

Brookline Experiments.

Comparative Efficiencies of System No. 1 (Aëration and Subsidence) and System No. 4 (Aëration and Contact).

The construction costs of the four systems in practice, including engineering, are estimated as follows:

Cost of Deferrization Plant and Appurtenances.

(Capacity, 8 000 000 gal. daily.)

System No. 1	$284 900
System No. 2	152 900
System No. 3	157 850
System No. 4	162 800

Apparently at Brookline, for deferrization and demanganization, it is not necessary to operate the tricklers submerged, and the iron and manganese in the effluent from Filter No. 4 decreased during the experiments until the end. It would be unwise, however, in view of the fact that the composition of the ground water,

supplied in part from beds irrigated with water pumped from the Charles River, varies greatly during the year, and because the complete removal of color is also desirable, not to provide means for partially submerging the coke if necessary. The experiments will be continued, but at this writing it seems as if the efficiency of deferrization by this method depended upon the accumulation of a film on the coke and the degree of aëration of the water, as shown by the dissolved oxygen.

The costs of operation with systems Nos. 1, 3, and 4 are estimated as follows. In estimating the cost of water by the different systems, we have assumed the capacity of the plant to be 8 000 000 gal. per diem and the average daily consumption to be 5 000 000 gal.

ANNUAL COST.

	System No. 1.	System No. 3.	System No. 4.
Fixed charges at 6 per cent....	$17 094 00	$9 471 00	$9 768 00
Fuel........................	1 343 00	1 712 00	2 080 00
Oil, waste, etc................	100 00	100 00	100 00
Cleaning basins and flushing tricklers..................	100 00	100 00	100 00
Scraping sand filters..........	323 00	510 00	121 00
Three filter attendants........	2 160 00	2 160 00	2 160 00
Superintendence, analyses, records, etc..................	1 200 00	1 200 00	1 200 00
Total cost of operation per annum..................	$22 320 00	$15 253 00	$15 529 00
Cost without fixed charges per million gallons.............	$2 86	$3 17	$3 16
Cost of water per million gallons	$12 24	$8 37	$8 51

That System No. 4 is to be preferred may be judged from the estimated cost of operation. This is influenced both by the higher construction cost of System No. 1 and the larger yield between scrapings of Filter No. 4. There was insufficient time before freezing weather to determine this latter factor exactly, as Filter No. 4 has not required scraping, but the following table will indicate the comparative estimated yields of the four systems.

System.	Average Yield between Scrapings. Million Gallons per Acre.
No. 1	347
No. 2	165
No. 3	220
No. 4	over 1 000

MIDDLEBORO EXPERIMENTS.

While the chief interfering substance at Cohasset is organic matter, at Middleboro it is manganese; both organic matter and manganese interfere at Brookline, but the small mass of iron increases the difficulty of deferrization.

Previous Experiments. During 1912 and previously experiments were made by the Massachusetts State Board of Health and others, and Mr. Clark tells me that they succeeded by intensive aëration, and filtration at a rate of from 7 000 000 to 10 000 000 gal. per acre per diem, in reducing the iron from 2.0 to 0.3 parts per million. The writer is unaware that the presence of manganese was considered as a factor in the problem. Upon being consulted by the water commissioners and fearing that manganese was present in the well water, the writer advised that the experiments be continued.

1913 Experiments. The experiments were made with the same filter which had been operated for the State Board of Health since October, 1912.

The experimental devices were arranged as follows:

1. A spray aërator discharging upon a trickler.

2. A trickler consisting of one barrel filled with a 2.5 ft. depth of 1 to $1\frac{1}{2}$ in. broken stone.

3. A filter containing a depth of 26 in. of sand, having an effective size of 0.285 mm. and a uniformity coefficient of 2.3. This filter was operated at a rate of 10 million gallons a day, and had a depth of only 8 in. of water above the sand. It was provided with a rate controller and loss of head gages. The sand area was 2.5 ft.

Results of Experiments. This plant was started on January 18.

In the beginning the filter clogged rapidly. The iron, however, was being reduced on an average from 0.90 to 0.18 parts per million, as shown with other results in the following table.

AVERAGE RESULTS OF OPERATION, EXPERIMENTAL FILTERS, JANUARY 13 TO 31.

(Parts per Million.)

Determination.	Well Water.	Trickler Effluent.	Filter Effluent.
Color	55	29	13
Iron	0.90	0.60	0.18
Carbon dioxide	33.9	16.4	18.5
Dissolved oxygen	4.81	8.83	6.81

By February 1 the filter had been scraped four times and a subsiding basin having a capacity equivalent to 1.5 hr. flow was placed between trickler and filter. The trickler which had been operating half submerged was raised so as to operate non-submerged. The average results after this change were as follows:

RESULTS OF OPERATION, EXPERIMENTAL FILTER, FEBRUARY 1 TO FEBRUARY 11.

(Parts per Million.)

Determination.	Well Water.	Trickler Effluent.	Filter Effluent.
Color	30	22	11
Iron	0.76	0.42	0.13
Manganese	0.50	0.40	0.30
Carbon dioxide	45.6	18.5	13.2
Dissolved oxygen	2.56	9.55	9.13

It was apparent during this period that the removal of iron was satisfactory; the filter still clogged rapidly (about every three days) and manganese passed through both trickler and filter and appeared as a black deposit of oxide, or manganese rust, in the little ditch which received the filter effluent. It was therefore decided to increase the contact, to remove the manganese, and

on February 11 another barrel filled with coke was added to the trickler equipment. The new arrangement was put in service on February 4. The results up to February 19 were as follows:

RESULTS OF OPERATION, EXPERIMENTAL FILTER, FEBRUARY 4 TO FEBRUARY 19.

(Parts per Million.)

Determination.	Well Water.	Trickler Effluent.	Filter Effluent.
Color	39	33	13
Iron	0.84	0.46	0.23
Manganese	0.93	0.99	0.86
Carbon dioxide	44.2	5.4	6.7
Dissolved oxygen	2.74	10.45	8.10

The filter effluent was still turbid with manganese, although by February 15 the reduction of dissolved oxygen in the filter was noticeably increased and scum on top of filter was appreciably darker. The period between scrapings had lengthened but slightly. It was therefore decided, chiefly in order to hurry the experiment, to increase the contact period by filling the subsiding basin with coke. This was done on February 20. The results of this change were as follows:

RESULTS OF OPERATION, EXPERIMENTAL FILTER, FEBRUARY 21 TO MARCH 14.

Determination.	Well Water.	Spray Aërator.	Trickler Effluent.	Basin Effluent.	Filter Effluent.
Color	52		28	24	13
Turbidity	16		6	5	5
Iron	1.35		1.5	0.35	0.21
Manganese	0.68		0.79	0.79	0.60
Carbon dioxide	48	40	5	4.5	5.5
Dissolved oxygen	3.30	—	10.70	10.32	9.28

During this period some oxidation was taking place in the filter, but the turbidity of the effluent decreased; the manganese

began to accumulate on the surface of the sand, and the periods between scrapings increased somewhat. More contact was evidently necessary, but as a half hour's contact with the submerged coke did not seem to effect any removal of manganese, the height of the trickler was increased 50 per cent. by placing another barrel filled with coke on top of the others. The total depth of trickler was now 6.7 ft. and there was submerged contact in addition. The spray nozzle discharged on this coke from a height of 20 in. The filtration through the trickler was increased to 75 million gallons a day. The immediate results of this change on the dissolved gases were as follows:

RESULTS OF OPERATION, EXPERIMENTAL FILTER, BEFORE AND AFTER CHANGES, MARCH 14.

(Parts per Million.)

Determination.	Well Water.		Trickler Effluent.		Basin Effluent.		Filter Effluent.	
	Before.	After.	Before.	After.	Before.	After.	Before.	After.
Carbon dioxide...	43.5	38.7	5.7	4.5	6.6	5.5	6.5	10.5
Dissolved oxygen.	3.01	3.01	9.75	10.82	9.50	9.84	9.5	9.89

RESULTS OF OPERATION, EXPERIMENTAL FILTER, MARCH 27 AND APRIL 23, 1913.

(Parts per Million.)

Determination.	Well Water.		Trickler Effluent.		Basin Effluent.		Filter Effluent.	
	Mar. 27.	Apr. 23.	Mar. 27.	Apr. 23.	Mar. 27.	Apr. 23.	Mar. 27.	Apr. 23.
Color............	45	45	40	38	12	10	10	10
Turbidity........	3	2	5	5	2	2	1	1
Iron.............	1.2	0.9	1.9	1.8	0.35	0.25	0.15	0.2
Manganese.......	0.75	0.72	0.95	0.9	0.75	0.55	0.38	0.25
Carbon dioxide...	44	48	5.0	5.0	5.5	5.3	5.0	5.0
Dissolved oxygen.	3.50	4.21	11.07	11.42	10.83	11.51	10.91	11.26

The plant ran without change until June 6. Immediately the operation of the filter began to improve, the period between rakings increased to double or more, and the filter was not scraped again. Simple raking restored the sand layer to efficient operation. On March 27 and April 23 the results were as shown by the preceding table.

The results for April 23 were so satisfactory that analyses were discontinued until June 6, when the experiment was stopped and samples of trickler, basin, and filter effluents were collected for analysis; the results were as follows:

RESULTS OF OPERATION, EXPERIMENTAL PLANT, JUNE 6, 1913.

(Parts per Million.)

Determination.	Trickler Effluent.	Basin Effluent.	Filter Effluent.
Color	15	10	4
Turbidity	8	5	1
Iron	0.90	0.40	0.20
Manganese	0.95	0.45	0.20
Carbon dioxide	6.0	4.0	3.0

These results confirmed the previous ones and exemplified the increased efficiency due to the accumulation of coatings on the materials in the trickler and subsiding basin.

Character of Coatings. The trickler was dismantled and samples of dried coatings from different points were analyzed with the results shown in Table VI.

TABLE VI.

SHOWING COMPOSITION OF COATINGS FROM DIFFERENT POINTS.

Source.	Top of Trickler.	Bottom of Trickler.	Bottom of Basin.	Surface of Filter.
	Per Cent.			
Iron	29.16	21.56	40.32	8.51
Manganese	1.82	7.69	3.41	10.15
Aluminum	5.19	3.39	2.54	6.78

This table shows where the work was done. The removal of the iron began at once and was nearly complete except for the final straining before the filter was reached.

The demanganization process began in the lower part of the trickler, but most of the manganese passed through the subsiding basin and was removed by the filters. Earlier in the experiments the manganese penetrated and discolored the filter sand; later the accumulation was largely restricted to the surface and the sand became clean again. At Brookline the sand is still discolored with manganese.

The precipitation of aluminum is interesting, and the writer is not aware that it has been noted before. It is evidently not so difficult to remove as manganese, but more difficult than iron. Strangely enough, the molecular weights of the oxides vary inversely with the speed of precipitation; that is, the metal which forms the heaviest oxide precipitates easiest. Aluminum, however, requires no oxidation, while the oxidation of iron and manganese must precede their coagulation and precipitation.

MIDDLEBORO PURIFICATION PLANT.

The design of the Middleboro plant was made during the experiments, and the plant was built during the summer of 1913; the contractor for the main structures was the Briggs Engineering and Construction Company, of Providence, and the low-lift pump was supplied by the Power Equipment Company, of Boston. The details of the design and construction were worked out and supervised by Mr. G. A. Sampson, with T. F. Dorsey as resident engineer. The plant consists of the following parts:

A DeLaval steam-turbine-driven, centrifugal pump, having a capacity of 1 000 000 gal. per day. This pump takes water from the present well and discharges it on top of the pile of coke, — a so-called trickler, — through a number of sprinkling nozzles.

A trickler built of concrete, 30 ft. in diameter outside measurements, and containing 10 ft. of coarse coke supported upon a concrete grill work, above the true bottom. The water from the trickler falls upon its true bottom and flows through a pipe into the settling basin.

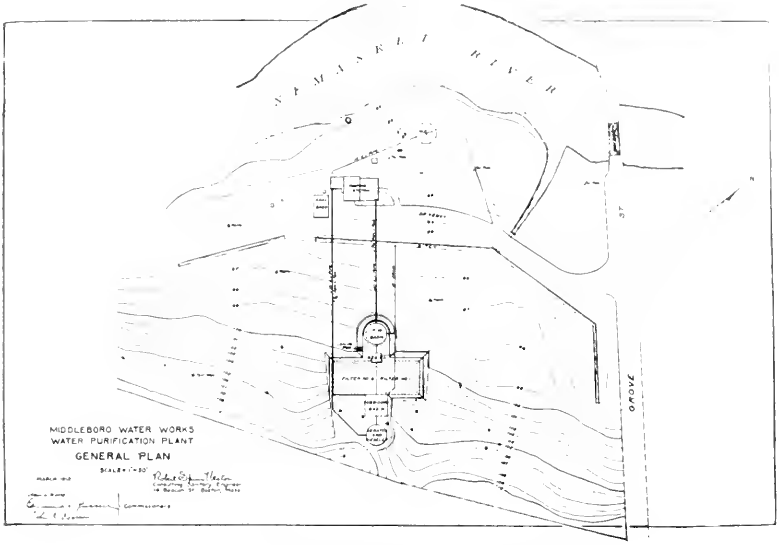


FIG. 3. *MIDDLEBORO DEFERRIZATION PLANT.
General Plan.

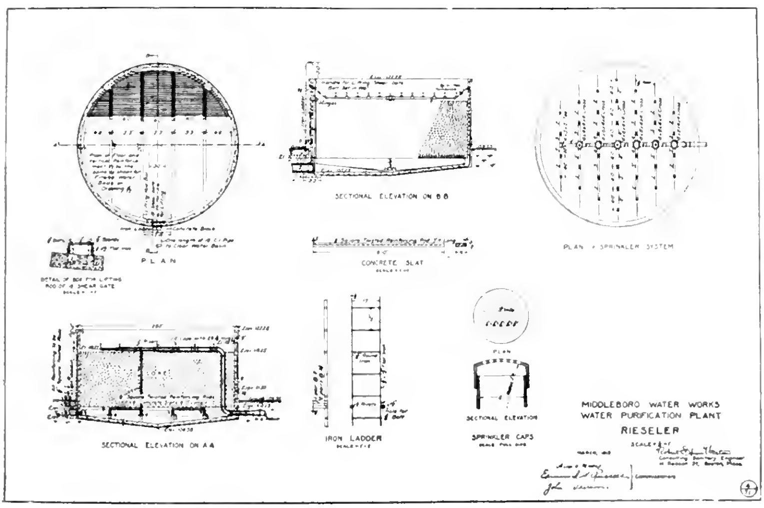


FIG. 4. *MIDDLEBORO DEFERRIZATION PLANT.
Coke Rieseler or Trickler with Aërator.

The settling basin is built of concrete and has a capacity of 40 000 gal. It is covered with a concrete roof and earth to prevent freezing.

From the settling basin the water flows into the two compartments of the filter, having a total area of 0.1 acre. These filters are simply concrete basins with groined roofs, covered like the settling basin with earth to prevent the freezing of the water in winter. On the bottom of the filter is laid tile under-drains covered with 12 in. of graded gravel, supporting in turn 3 ft. of medium sized sand.

From the two filters the water flows into a regulator house in which are located all of the valves and gages for operating and regulating the filters.

From the regulator house the water flows into a filtered water basin which holds 42 000 gal. This is large enough to enable the pumps and filters to operate regularly and to supply the hydrants during ordinary fires. For fire purposes this supply is at the rate of at least 1 000 000 gal. in twenty-four hours, or twice this amount during one hour. The present consumption is about 335 000 gal. per day; and the maximum consumption for any one day has been 873 000.

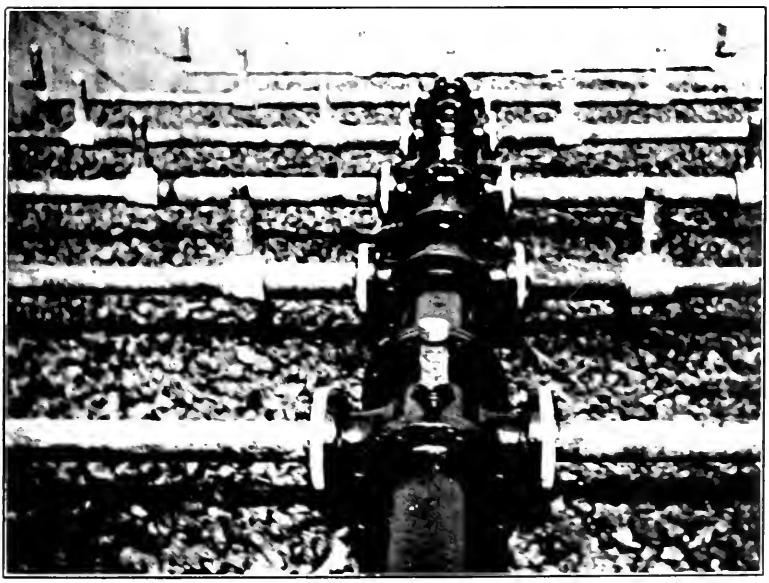
Of these various parts the aërator and trickler are alone worthy of special comment, for although the filters embody some special features, these may be readily apprehended by inspecting the plates.

Aërator and Trickler. The aërator consists of a system of piping connecting the discharge from the low-lift pump with thirty-seven 2-in. nipples. On each nipple is screwed a cap drilled with twenty-four $\frac{3}{16}$-in. holes and pressed to make the upper surface convex and the axes of the holes radial. These sprays discharge upwards, discharging the water on the surface of a layer of coarse coke, 10 ft. deep, contained in a concrete tower 28.3 ft. in diameter.

The coke is supported upon 2-in. by 6-in. reinforced concrete beams spaced 2 in. apart and supported upon a beam 6 in. wide, around the inside of the trickler wall and also upon four cross walls, 6 in. wide, resting on the floor.

The floor slopes to a channel leading to the 18-in. cast-iron

MIDDLEBORO.
Showing Aërator in Operation.



MIDDLEBORO.
Aërator Piping.

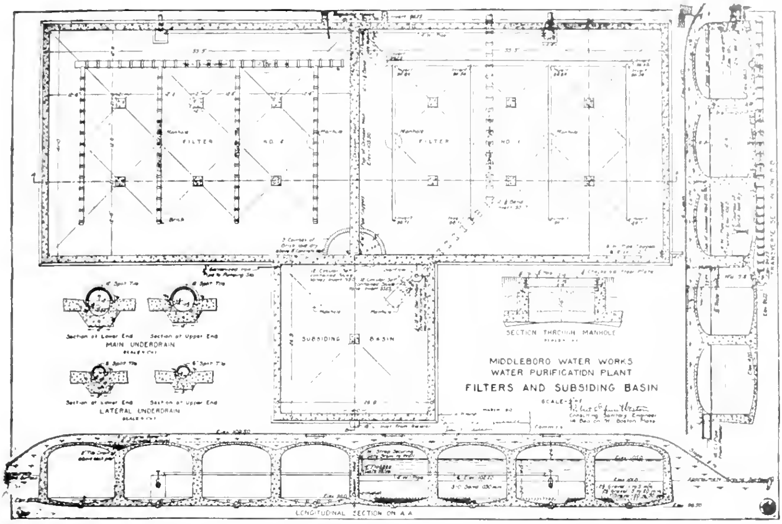


Fig. 5. Middleboro Deferrization Plant.
Filters and Subsiding Basin.

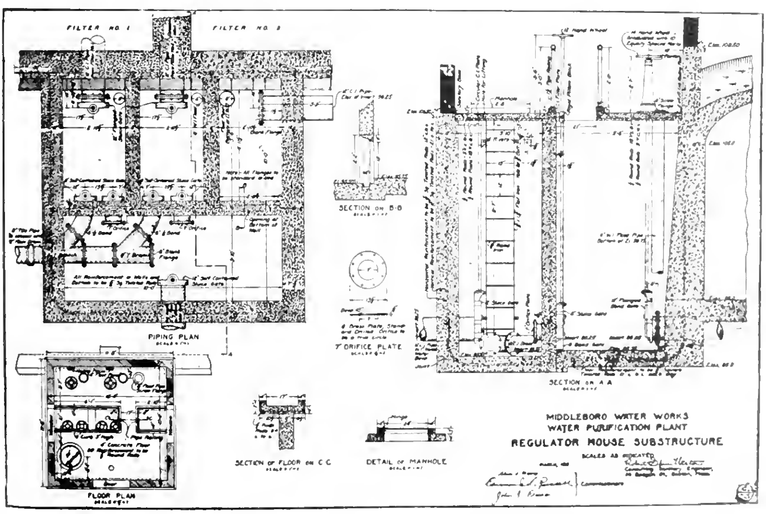


Fig. 6. Middleboro Deferrization Plant.
Regulator House Substructure.

pipe which connects with the subsiding basins and filters. A shear gate provides for the closing of this outlet, when the trickler may be filled; then the valve may be opened quickly and the excess of accumulation in the coke flushed out, through the subsiding basin and into the drain. It is not expected that flushing will be required oftener than once a year.

Filters and Appurtenances. The two filters have no doors and runways, but special sand boxes have been designed, into which the sand removed by scraping is dumped and washed out into bins placed outside the filter. The sand used in the filters had an effective size of 0.31 mm. and a uniformity coefficient of 1.80. It was a natural bank sand which did not require washing.

The regulating devices are of the orifice type and indicating rate and loss of head gages are provided for each filter.

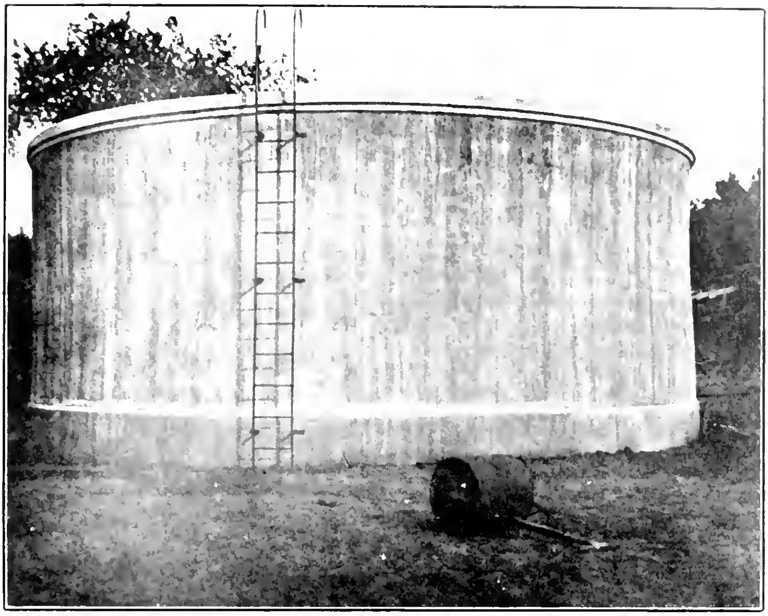
Cost. The complete plant has cost about $18 000, including engineering.

Results. The filters started on September 26, 1913. They had been raked twice and scraped once prior to January 12, 1914. The yield for this first run was 40 million gallons, or 400 million gallons per acre. The filters have been in operation so short a time that the effluent varies in quality considerably, particularly just before and after scraping or raking the filter. The average results are as follows:

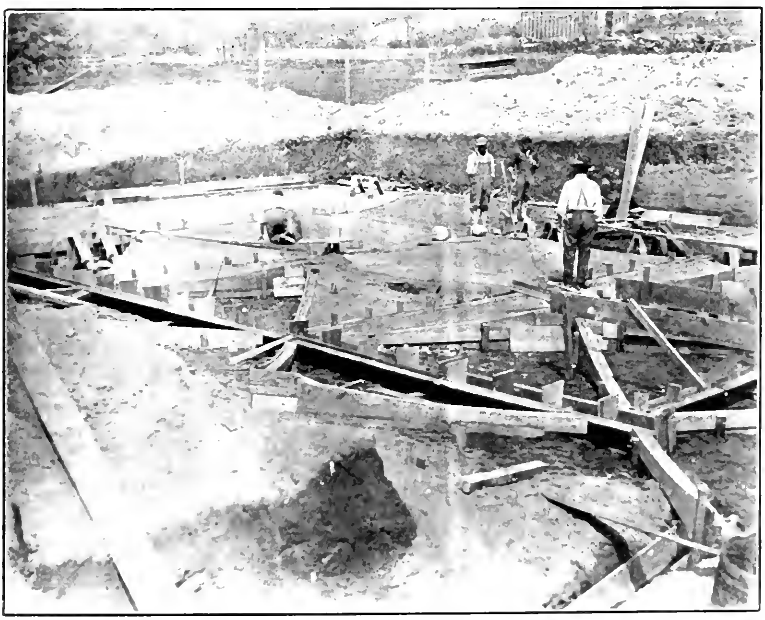
AVERAGE RESULTS OF OPERATION, MIDDLEBORO,
FIRST RUN, SEPTEMBER 26, 1913, TO JANUARY, 12, 1914.
(Parts per Million.)

Determination.	Well.	Settling Basin Effluent.	Filter Effluent.
Color	48	22	5
Turbidity	5	3	1
Iron	1.62	0.46	0.17
Manganese	0.67	0.36	0.27
Hardness*	27.3	——	23.4
Oxygen consumed	1.79	1.53	1.05
Carbon dioxide*	41.0	4.2	4.6
Dissolved oxygen*	2.95	10.20	9.55

* One determination.



MIDDLEBORO.
Rieseler or Trickler.



MIDDLEBORO.
Placing Concrete in Filter Bottom.

The above results bear out the conclusions of the experiments very well, although the manganese had not been reduced as low as it was later, on January 22, when it was reduced from 0.85 part per million in the well water to 0.10 in the filter effluent. After scraping, the iron increased to .35 part in the filter effluent, but the latest result, by the State Board of Health, on February 1, shows it to be 0.18 part per million, — all that could be desired.

Should the organic matter in the well water increase, the trickler may be arranged to be operated partly submerged. So far this has not been necessary, although the "oxygen consumed" is now considerably higher than during the experiments. The removal of the carbon dioxide and the practical saturation of the water with oxygen are worthy of notice; also the great share of the work borne by the trickler, thereby greatly lessening the cost of filter operation.

GENERAL CONSIDERATIONS.

In this paper have been given the results of experience with three waters containing iron and manganese, one of which could not be aërated to saturation without causing some of the iron and color to escape removal, and one of which required complete oxidation to effect a satisfactory removal of manganese. The third water demands complete aëration and long contact as well, and contingencies may arise when this contact should be effected with the material submerged.

Other things being equal, it is well to remove the carbon dioxide as completely as practicable in order to prevent subsequent corrosive action of the water upon the distribution, consequently aëration and contact in a trickler should be employed as far as possible, and submerged contact when this method fails.

Naturally, the choice of methods depends upon the character of the untreated water, and if the writer has made it plain that not only do different supplies vary, but that even the water from the same well may require a varying treatment, he will feel repaid.

Regarding the choice of filter, it may be stated that properly treated water can be filtered either through slow or rapid filters, with good success. The high rates possible with a sand filter, and the infrequency of cleaning when the pretreatment is ade-

quate, usually makes it more economical than the mechanical filter; furthermore, when manganese is present, it undoubtedly gives more uniform results.

DISCUSSION.

MR. ALLEN HAZEN. I first came in contact with this iron removal problem about twenty years ago, when I saw some of the German works that Mr. Weston has described. Afterward I had something to do with some of the earlier attempts to introduce these methods in this country. If I am not mistaken, the earliest plants in which iron was removed from ground waters were on Long Island and along the New Jersey coast. The waters in these two localities are practically the same chemically, and the iron was removed very easily indeed, in the way that Mr. Weston mentioned in connection with Marblehead. It was simply necessary to aërate and filter the water. It did not take a great deal of aëration, and almost anything which could be called a filter would take out the coarsely precipitated iron. It may be that the ease with which the iron was removed in those first cases served to make us think that the problem was easier than it really was. The difficulties were found later when other kinds of waters were tackled.

The plant at Superior, Wis., which Mr. Weston has mentioned, and where he struggled with the problem in an experimental way through some months, was one of the early ones which showed difficulties. The water carried a moderate amount of iron, and after aëration and filtration the iron was not separated in the way that it was found to separate in New Jersey and Long Island. A plant was built, however, upon these same general lines, with some modifications suggested by Mr. Weston's experiments, and it has operated with success up to the present time. The removal of the iron was not as complete, however, as in the other cases. The New Jersey and the Long Island plants removed every trace of iron. The Superior plant was not capable of doing this, and the effluent always carried an appreciable amount. The iron which was left seemed to be so firmly combined with organic matter that it caused no practical trouble, and from the standpoint

of the water company and of the water takers the plant has been eminently successful.

I saw the plant in Superior two weeks ago, and it is interesting to note that in the course of the fifteen years that the plant has been in operation the iron has gradually decreased in the well-water supply so that at present there is only about a third as much as there was when the plant was first put in operation.

Mr. Harry W. Clark (*by letter*). — In this connection I can say that experiments upon the removal of iron from ground waters in Massachusetts began to be made under my charge about eighteen years ago, and the report of the Massachusetts State Board of Health for 1899 contains an article by me, entitled "The Occurrence of Iron in Ground Waters, and Experiments upon Methods of Removal." These experiments showed that aëration and sand filtration at high rates were entirely successful in such removal with the majority of the waters experimented with at that time, but from one of them, the then Provincetown supply, iron could not be successfully removed by the treatments tried. The interference of carbonic acid and organic matter was discussed in that paper, but the influence of manganese was not then recognized. However, at the time of the experiments carried on at Middleboro by this Board in 1911 and 1912, this factor of interference by manganese was well understood and our experiments, as stated by Mr. Weston, were successful in freeing the Middleboro water from iron and cloudiness. During the past eight years numerous determinations of the amounts of manganese in ground water supplies have been made in these laboratories and its importance in connection with water and water purification noted.

PROPER CHARGE FOR FIRE PROTECTION SERVICE.

TOPICAL DISCUSSION.

[*January 14, 1914.*]

Mr. Francis T. Kemble.* I would like to bring up the matter of private fire lines, with an idea of seeing what our members think is a proper charge for such service, what should be considered an adequate ready-to-serve charge. The private fire line situation at the present time, when architects and underwriters are asking for mains and double mains, capable of delivering large volumes of water, to be carried into buildings, is a pretty serious one.

We have not only to be ready to furnish a good deal of water, but we have to run a considerable risk if anything happens to these lines, and perhaps takes the pressure off a main. We had one case a year ago where a building used as a plant for making moving pictures went up in a hurry. There was a 4-in. line running in there, supplied from a small main, the wall came down on the gate so that we could not get at it, and the line running free in the building took the pressure off our main.

It seems to me that a water company ought to make a pretty good readiness-to-serve charge.

The President. This is a subject which has been discussed for many years, and has been a troublesome one to all waterworks superintendents. Many of them think that fire service pipes running into a building are often a great menace to the water supply, especially in case of a conflagration where buildings will come down, and where on account of the narrow streets it is impossible to get in to shut the water off. I hope that there will be a free discussion of this interesting subject.

Mr. Frank E. Merrill.† This is a subject which interests me at the present time, because we have an application pending

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* Secretary New Rochelle Water Company, New Rochelle, N. Y.
† Water Commissioner, Somerville, Mass.

for a 6-in. fire service off a 6-in. dead-end main. I should like to ask the members who are interested in these matters what they would do with such an application if it should come to them; not only as regards the charge for service, but also as to granting a request for so large a service as 6-in. under the conditions existing?

MR. KEMBLE. The suggestion is made to me that in such a case you put a meter on, but that does not mean anything really, because they might never use any water to speak of. I contend that you ought to have a pretty good ready-to-serve charge.

MR. CHARLES H. TUTTLE.* The Bristol and Warren Water Works, which is a private corporation, has contracts with the towns which call for the furnishing of water for fire purposes free. Whenever application is made for a fire service we insist upon a meter going on to the service. For all water used through that meter we get our regular rates, but what is used for the actual putting out of fires is furnished free. The fire services are put in at the expense of the person making the application, and the company is at no expense in the matter. We put it in and charge the actual cost plus a reasonable percentage for overseeing the job.

MR. H. O. LACOUNT.† Mr. President, whenever I have occasion to think along this line I am very much impressed with the fact, which I think is being shown, that one of the best ways to prevent a conflagration is to very freely supply fire protective equipments with water, and to do that we must have the fire service connection. Now I would not advocate putting in a fire service connection larger than the street main, certainly, and I think that in many cases we do not need to have a pipe as large as the street main. I, however, think we can go too far the other way, and have our sizes too small to do any real effective work, considering the amount of protection which is to be called for at the other end of the fire service connection.

The matter has been discussed a great many times with reference to the question of the size of the connection. That from an engineering standpoint is a very interesting study. I think that in all of this work good sense should prevail, and that we ought to

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* Superintendent Bristol and Warren Water Works, Bristol, R. I.

† Engineer and Assistant Secretary, Inspection Department, Associated Factory Mutual Fire Assurance Companies.

lay out our service connections not only with reference to the size, but to location, so that they will be least liable to be seriously crippled in case of a falling wall. I believe that much could be done along that line in the way of good engineering and good horse sense in placing our controlling valves on these fire service connections.

I appreciate that what I am saying is not with direct reference to the question that has been asked, and that is with reference to the charge. No doubt there are two sides to the question, but if we overdo the charge feature we at the same time will cripple the efficiency of our fire protection, because beyond a certain amount you penalize what many people, at least, believe is a good thing, and especially a good thing with reference to the protection of a congested area. Personally I am looking for the time when fire protection will be much more mandatory than it is at the present time, with purely the point of view of preventing these serious hazards to our congested areas which now and then do come to a head in the form of conflagrations. Just as soon as private fire protective equipments become in any section mandatory, there of course will be the necessity of securing an adequate water supply, and all these other questions will then be raised again as to what is the proper size of connection, what the proper charge, etc.

I have no doubt that some charge is reasonable, but from the tone of voice in which the question was asked I feel that the charge which, perhaps, the gentleman would advocate would be excessive, according to my view of the matter. I do not think that I am ready offhand to suggest what the charge should be in any given case, without having a chance to study its particular conditions, because I believe thoroughly that conditions will alter the case. Not only from the standpoint of good protection, — good engineering with a view to adequate protection, — but from the standpoint of what is fair to be paid for these privileges, it will be a matter of very considerate study to get at that one best opinion and best solution of the problem which all fair-minded people no doubt are striving to reach. But do not put in fire protection and expect that without the supply it will give a good account of itself, because you must have the water; and I fancy that even with an

occasional broken fire service connection we will extinguish our fires in the long run with much less water than we will in the other way, which is through hose streams at a distance and under the most unfavorable conditions which you could well imagine. If you apply your water promptly and directly at the seat of the fire you will use the least water and have the least fire loss. Therefore, favor the private automatic sprinkler equipment and do not tax it unreasonably.

MR. R. S. WESTON.* It might be of interest to the gentleman who asked the question to read Mr. George G. Earle's† paper describing the method of charging for water used at New Orleans. The charges for water itself are uniform to all consumers, but the charge for the use of the service — that is, the readiness-to-serve charge — varies with the size of the service. That is to say, a 6-in. service would cost much more per annum than a ½-in. service. I believe there was also some extra charge to cover the cost to users of special fire protection. I think one in considering charges for fire protection should bear in mind that the cost of supplying fire service in the case of small works is very often 90 per cent. of the total cost of supplying water; and it would seem as if this fact would be a sufficient reason for compelling those who benefit by the costly provision for fire service to pay something like their just share of the cost of supplying water.

MR. CHARLES W. SHERMAN.‡ I do not feel ready to offer any suggestion as to the actual charge, but it seems to me that some combination of the suggestions that have been made by Mr. Lacount and two or three of the preceding speakers might, perhaps, serve as a basis for working out such a charge. It does not seem to me that there should be any charge for the water actually used for extinguishing fires. I believe that fire service pipes should be controlled by suitable meters; and that water used for any other purpose than extinguishing fires should be charged for. I believe with Mr. Lacount that the fire service pipe should be of sufficient size to be of value if a fire actually does occur. I think that his suggestion as to the location of the controlling valve

* Consulting Sanitary Engineer, Boston, Mass.

† Proc. A. W. W. Assoc. 1911, p. 173.

‡ Assistant Engineer, Metcalf & Eddy, Boston, Mass.

might, perhaps, be carried a little further and include the installation of additional main line valves each side of the branch, if such are not already in existence, and that it would not, perhaps, be unreasonable, in some cases at least, if the cost of those additional main line valves were figured in as a part of the installation cost of the private fire line.

Whatever charge there may be for fire protection should, it seems to me, be a readiness-to-serve charge. How much that should be is something for each works to figure out in view of the local situation; but obviously it should not be so large as to hinder the putting in of such a service as will do the work. Whether a charge made up by including the whole cost of installation, including additional main line valves, and a small annual readiness-to-serve charge, would not work out equitably, is the suggestion I have in mind.

Mr. Patrick Gear.* This subject is one in which we are very much interested in the city of Holyoke. In our report for the year 1913, which is not ready for publication, there is a suggestion that we investigate the matter of charging the manufacturers for fire protection in their plants, where they have water pressure on sprinkler heads at all times, and for which they do not pay a cent to the water department. If the manufacturers get their insurance rates from 20 to 30 per cent. cheaper than formerly, it seems to me that they should be willing to pay the water department some revenue for supplying this water pressure.

If you should talk with any manufacturer or any of his men, they will tell you that they do not use any water; but if we have an occasion to shut off the water for two or three hours to make some repairs, then a man is needed to shut and open the dampers, for they will not operate unless the pressure is there. This is another case of where the water department is furnishing water pressure and receiving nothing for so doing.

I would like to hear from some of the other superintendents with reference to this matter, who meet with the same conditions as we do, to learn whether or not they have a fixed rate or charge for same.

* Superintendent Water Works, Holyoke, Mass.

Mr. Robert J. Thomas.* In Lowell we do not charge anything for the water used for the extinguishment of fires, but we do insist on a meter being placed upon the services, so that we may be able to charge for water used for other than fire purposes. That is about the only regulation we have, excepting that we will not tolerate any connection between the city pipes and the pipes of private water systems.

Out West in many places they do charge for fire services. I think in Indianapolis and several of the large cities they begin with a 4-in. pipe, charging, say, $25, $50 for a 6-in., $75 for an 8-in., $100 for a 12-in. In some cities they restrict the size to 6 in., and in many places they will not allow a larger connection than 4 in. The charge for fire services, take it the country over, but especially in New England, is very moderate. I believe that all water works, public or privately owned, should insist that they be protected, and no water used for other than fire purposes unless it is charged for.

Mr. Carleton E. Davis.† It is customary in Philadelphia to furnish fire protection supply as distinct from domestic supply without charge. A bond, however, of $400 is required, stipulating that the water shall not be used for other than fire purposes. On fire lines there is generally a by-pass line on which is set a meter one inch or thereabouts in size, which is supposed to indicate when water is used for other than fire purposes. Sometimes this by-pass meter works successfully and sometimes it does not.

We found recently an interesting case where one of the prominent newspapers in the city had a 4-in. fire line. They were under the customary bond not to use the water for anything but fire purposes. We found they had a 2-in. connection from that fire line supplying water to the type foundry. Of course they objected seriously when a charge was made on the schedule basis for the size of the fire line.

The underwriters in Philadelphia have recently proposed to use the high pressure fire system to furnish water for sprinklers. The city has two high-pressure systems, one covering a portion of the mill district and one covering a portion of the business

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*Superintendent of Water Works, Lowell, Mass.

†Chief Engineer, Bureau of Water, Philadelphia, Pa.

district. The domestic pressure in the bulk of these territories is low, very rarely going above 50 lb., and often much less.

The underwriters have suggested maintaining a permanent high pressure on the fire-line system and connecting it with the sprinklers. Objections have been offered to this proposal. One serious objection, which is of the same nature as that suggested by Mr. Thomas, is that one of these high-pressure systems is supplied with raw water from the Delaware River. Of course it would be difficult to keep the two systems of pipes inside the buildings distinct. The temptation to draw from the high-pressure lines for other than fire purposes would probably be too strong in many instances.

An objection has been raised as to whether the sprinkler heads would stand the high pressure which would be put upon them when the system is in use in time of fires. The underwriters have recently conducted some experiments to determine the relative efficiency of streams under different heads. The results of those tests are not yet available.

Mr. John Doyle.* In Worcester the Water Department requires all water to be metered, where there are underground connections. For instance, if the connection is 50 or 60 or 100 ft. inside of the property line of the manufacturing plant there is installed a detector meter. Where we put in fire pipes and the building abuts on the street line, we go in with both connections. We have a high and low system in Worcester in the business section, and we bring both lines inside the property line into the building proper, and the sprinkler system is connected there, both lines being brought together, and we install valves and a small meter which acts as a sort of detector for small streams, where there is any liability of small streams being used off the sprinkler system through the building. But in all cases the department requires that detector meters be put on all underground lines. So the liability of any inside connection being made with the system is rather remote, because with our system of a small detector meter, as we call it, put upon the alarm system inside the building, it will show when any water is being used. So far as I know, there is no charge for any water used on the sprinkler system,

* General Foreman, Water Department, Worcester, Mass.

unless it might come about that there might be an excessive amount used. We also have an inspector who visits the fire systems once a month and makes a record of his inspection for the water commissioner, and any excessive use of water is looked after very closely. Furthermore, in all cases we seal the valves inside the buildings, and if the factory owner or manufacturer has occasion to break the seal on any of those valves, he is supposed to notify the water department immediately that he has done it, and our inspector immediately goes there after receiving the notice and reseals the valve. So far as I know, there has no charge ever been made for water used for fire purposes in any building where there is a sprinkler system.

MR. WILLIAM SULLIVAN. I should like to add one query to those which have been put. My question is, whether a charge is ever made for the amount of water which is used in the inspection of private supplies, these hydrants and standpipes, etc. Periodically the insurance inspectors come around and test the systems and use considerable water, so I want to add that query to the others.

METHODS USED TO LOCATE HIDDEN LEAKS IN UNDERGROUND PIPES, WITH SPECIAL REFERENCE TO PIPES WHOSE EXACT LOCATION IS UNKNOWN.

TOPICAL DISCUSSION.

[*January 14, 1914.*]

Mr. Patrick Gear.* We are trying at the present time in Holyoke to account for an unusually high consumption in one of our residential sections.

The average daily consumption in one section of the city which has 6 000 people is 58 gal. per day per capita, which we are satisfied is a fair and proper amount; but in a similar section containing 5 000 people, the daily per capita consumption is 150 gal., which we feel is altogether too large.

An inspection of the fixtures in this district showed them to be in very good condition, and there is no indication on the surface of any leak, nor is there any lack of pressure in any particular locality.

We became satisfied early in January that some condition existed which should be discovered and rectified if possible, and made a few tests in the hours of the night, when the consumption would be smallest. Our method was to shut all the gates in one or two blocks in the section under investigation and then meter the water used in the blocks shut off, feeding through a fire hose with meter attached from a hydrant outside the section to another hydrant inside. We found various sections to be using at the rate of 28, 18, 14, and 12 gal. per day per capita, perhaps about one third of the area of the whole district.

Owing to the cold nights and consequent freezing of the hose, we decided to postpone further tests of this kind till more suitable weather conditions prevailed if the cause of the high rate was not discovered before then, and meantime we are having tested the 16-in. meter at the reservoir, from which this supply is drawn.

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* Superintendent Water Works, Holyoke, Mass.

Mr. Gear (*by letter*). The test of the meter by the National Meter Company was reported as satisfactory. By the time we received this report from the meter company, the ground was frozen pretty deep and we did not care to run any extra chances turning on high service in cold weather, and so we delayed any move in this direction until spring.

Meanwhile our engineer computed how much storage we ought to have in the reservoir, on the basis of collecting the same as on the Tucker Brook watershed for 1913 and drawing out from the reservoir the amount shown by the meter, and found we had in storage about 200 million gallons more than the computation would show.

We cut the pipe and disconnected the meter at the throat, and found a piece of 2-in. plank, seven inches square, which forced twice as much water through the registering part of meter as was actually used. This was the cause of all our trouble. We found no leaks and everything is all right.

USE OF THE FORCE PUMP IN CLEANING SERVICE PIPES.

[*February 11, 1914.*]

TOPICAL DISCUSSION.

Mr. George H. Finneran.* Those of us who have to do with the distribution of water are familiar with the complaints, "No force," "Partial stoppage," "Complete stoppage," etc. Where lead pipes are used to supply the consumers, the trouble is usually located at the corporation cock or tap, where rust or corrosion accumulates. It comes in from the main and lodges in the cock. Now the usual method of relieving a situation like that is to dig down to the cock and clear it out, and as a rule the results are satisfactory. But that is a rather costly operation in large cities where pavements are expensive, and the public convenience also suffers. However, I think we have devised something that practically solves the problem.

It is a high pressure, lever-handle hand pump, — a small affair that can be carried around by a plumber and his helper. We make a connection with the service pipe just inside the cellar wall, usually at the stop-cock. We use the stop-cock to control the water from the street. Previously to connecting the pump to the supply pipe we insert in the supply pipe a wad of paper. That is the essence of the operation. In fact, it is the secret of its success. This wad of paper completely fills the interior of the supply pipe. We then couple the pump to the supply pipe and are ready to proceed. There is one other thing necessary, — we have to supply water to the pump. It is a pressure pump, and while it will draft a little, yet you get better results by feeding it with an ordinary force pump which drafts from a pail of water. Of course the supply pipe is filled with water from the pump to the street, and any extra water that is pumped in makes a pressure and drives the wad of paper out towards the corporation

* Assistant Superintendent Water Service, Boston, Mass.

cock until it meets the obstruction. There may be a very small water-way through the obstruction, perhaps the size of a pinhole or perhaps larger, but the wad of paper is forced against the rust or corrosion, and completely dams up the little waterway, thus making a complete stoppage. A few more strokes of the pump and sufficient pressure is accumulated to break down the entire obstruction and carry the rust or corrosion and the wad of paper into the main and thoroughly clear the cock.

The removal of stoppages in this way has proved very satisfactory. I have in mind a case where it required seventeen minutes to fill a pail or a vessel that contained one cubic foot of water, and after the clearance the same amount of water was drawn in twenty-three seconds. The improvement was well worth the effort.

We also have found it efficient in clearing out iron pipes inside of buildings. It is desirable to have an open end to your iron pipe. The wad of paper is inserted in the pipe and the pump applied. As the wad proceeds it scours the walls of the pipe and carries the rust with it, and we get quite an accumulation. We save it sometimes and weigh it to see how much there is. In one case recently we cleared $3\frac{1}{2}$ lb. of iron rust out of 10 ft. of 1-in. pipe.

At first, while we were experimenting, we simply used ordinary newspaper for the wad or the pellet, but we didn't think it advisable to continue using that. Sometimes it was a "yellow journal," and as a general proposition it was not very sanitary, so now we use good quality tissue paper. It is compressed very hard, but the moment it gets out into the main it unfolds and dissolves and is carried away somewhere — through a hydrant, let us hope. It is a simple operation, the prime factor of which is the little pellet which for the time being creates a complete stoppage, where prior to the operation there was only a partial stoppage.

Mr. Frank L. Fuller. I should like to ask how this works where there is a hard corrosion, such as we sometimes see when we take out old iron service pipes. I should not suppose that could be removed, or that a wad of paper could be forced through it.

Mr. Finneran. Oh, yes; it will take out the very hardest mass of corrosion. We have cleared cocks where, without this operation, it would have been necessary to take an instrument and drive it out. Of course the water helps to dissolve and soften the corrosion. This pump, by the way, has produced a pressure up to 1 000 lb., although we have never used as much. I think that the ordinary lead pipe you find in the street would not stand such a pressure. As a rule we do not find it necessary to use over 150 to 200 lb. pressure. We used to carry a gage on the pump at first, and I think the very highest pressure we employed was 300 lb. Some of our stoppages were corkers; they were almost as hard as the brass that the cock is made of.

Mr. T. G. Hazard, Jr. I would like to ask the gentleman what would happen in case the service pipe from the main to the cellar was decidedly smaller than the pipe leading from the cellar into the house; that is, if the pipe where you made your connection with the pump was one inch and the service in the street was, say, half an inch? Would there be any danger of the paper pellet stopping up the pipe entirely at the curb cock?

Mr. Finneran. The wad of paper would soften and accommodate itself to the smaller area. That is, it becomes plastic after immersion. Of course at first the paper is very hard, but the longer it remains in the water the softer it becomes, and it accommodates itself to the shape of the pipe and the condition that it meets.

Mr. George A. King. As I understand it, this wad of paper simply stops up the hole entirely, so that you can get the pressure of the pump to take effect. The paper doesn't clean the pipe, but it is the pressure which cleans the pipe.

The President. No; the paper cleans the pipe.

Mr. King. Could not we clean it without the paper, if we had the force?

The President. There are a number of ways of cleaning the pipe, Mr. King. I speak not from a practical point of view so much as from the point of view of my own experience since Mr. Finneran and the others have started this method. I know that where we used to have innumerable complaints of stoppage they are becoming negligible now, for the simple reason that the pipe

can be cleared so quickly and so easily without digging. The practical result from my point of view is an almost entire stopping of complaints, for it is the simplest thing in the world now to clean a pipe. How long a pipe have you cleaned, Mr. Finneran?

Mr. Finneran. About 50 ft. is the longest.

Mr. George A. Stacy. I should say that this experiment, or this fact, can be easily demonstrated by anybody who is afraid to try it underground by taking some pipe that he has taken out and demonstrate to himself in the shop the actual working of this operation. When a man who is a practical man, engaged in practical work, comes here and says he does this thing and knows that it is so, I believe that there is something in it, — certainly as much as if he had got the information in Germany or at some school. I hope, Mr. President, that we will have more of this sort of thing, for it will seem like old times when we get back to it.

Mr. Coggeshall. I heard the other day that Mr. Finneran has contrived an apparatus whereby he can take his automobile to where there is a large gate, and by rigging up the automobile in some way he can use its power to open or shut the gate. I think that is a pretty good thing, and I would like to know more about it. I think I shall send my master mechanic up to his shop to look into it.

The President. I might say, Mr. Coggeshall, that that is our method of opening and shutting large gates. I do not want to use all our thunder at once, but that will be described fully in the near future.

The President. I might say one thing in the line of Mr. Stacy's remark that he hopes there will be more of this sort of thing, and that is that I want to notify the men here to-day, who are in touch all day long with these practical matters, that we expect to hear from them, and that we are going to try very hard to get them to speak to us, because I seriously and honestly believe that there is a very great deal of value which we have lost in the last few years in not following up this idea more and getting this information out.

Mr. F. F. Forbes. I would like to inquire where you can purchase this pump? It must be a special pump to get a thousand pounds pressure.

Mr. Finneran. We had a pump made by the Blake Pump Company. It is not an ordinary pump; you cannot go into the market and buy it. It is a specially made pump. We used it for years in our machine shop, testing large valves that we make up to 24 in. It is a high-powered pump. The water space is very small, it will not pump much water, but it will pump it at a great pressure.

The President. I think that there should be a gage attached between the pump and the pipe. We have depended up to date on the experience of the men in judging about what the pipes will stand, and they have never yet burst a pipe, but theoretically, certainly, there should be a gage.

Mr. Sherman. Is it an expensive pump?

Mr. Finneran. About fifty dollars. We had six made, which cost us three hundred dollars. We made a price with the makers. It is a well-made pump, and it will last indefinitely. There is no wear to it.

Mr. Fuller. I would like to know if an ordinary boiler testing pump, which throws a very small amount of water but under, perhaps, 200 lb. pressure, and costing, perhaps, fifteen dollars, would not answer the purpose.

The President. I have no doubt but that it would. There is no doubt but that a pump entirely satisfactory can be bought for very much less money than we paid.

Mr. Coggeshall. I should like to say that that is just precisely what we use in our department, — an ordinary boiler testing pump; and while we haven't got quite so good results, perhaps, as Mr. Finneran has obtained, it has done us mighty good service in cleaning out service pipes when the ground was frozen, and where we had to do something to augment the supply.

Mr. Patrick Gear.* A meeting like this, where anybody can talk on any matter he has a mind to, will give one an idea of the troubles somebody else has and how he overcomes them.

I have had that sort of pump for years, and am going to try this experiment when I get home. We have used this pump when we were notified that the water had suddenly been shut off in some building and we had a notion that the service pipe was ob-

* Superintendent of Water Works, Holyoke, Mass.

structed by fish. We would hitch this pump on to the service in the cellar and have a gage on it so we would not get our pressure too high and break anything. We would then shut a gate in the street, open a hydrant, apply the pressure and would generally get an eel through the hydrant. Our first attempts to free services in this manner were made without opening a hydrant, and, while we were successful in removing the obstruction from the service in question, we would get into trouble in some service farther along. By opening the hydrant we had no more trouble and have removed eels two or three feet long. We have never had any idea, however, that the use of this pump would clear out the service pipes of anything but large obstructions of this kind, and I feel well paid for coming down here to-day and learning that it will.

We all know that there is probably no class of men who carry more in their heads than water-works men, and all of us who are connected with water-works departments know that there is no class of engineers who are more expert or specialized in their business than water-works engineers. We have had as our President one of the most eminent engineers in the country, who has just successfully completed one of the biggest engineering jobs in the world, compared to which, so far as engineering skill is concerned, the construction of the Panama Canal was very simple, and yet we did not think anything at all about it.

The President. I would say to Mr. Gear that I feel confident that he will find that it has paid him to come here. We in Boston for many years have been using a force pump for cleaning services, but we look upon this wad of paper in connection with the force pump as a discovery, so far ahead of the old force-pump method that there is no comparison at all.

ARE TRENCHING MACHINES WORTH CONSIDERING IN EXCAVATING TRENCHES IN CITY STREETS?

TOPICAL DISCUSSION.

[*January 14, 1914.*]

THE PRESIDENT. I don't know whether any one has had any experience in trying to use trenching machines in city streets, but there are a good many engineers present here this afternoon, and some of them should have had experience on this subject and should have something to say.

MR. HARRISON P. EDDY.* It is a pretty broad subject, Mr. President, and there are so many things which can be said about trenching machines that I hardly know where to begin. Of course there is no question but that some type of trenching machine is very desirable in digging many earth trenches. Most water pipes, however, are laid pretty close to the surface, so that the quantity of earth to be moved is relatively small.

The Carson trenching machine, of course, is one of the types which is very familiar in this part of the country, and is of very great assistance in narrow streets, where the trenches are deep and wide. This applies more particularly to sewer trenches perhaps, for which I think the machine was originally designed, although there is no reason why it is not applicable to water trenching under some, although rather exceptional, conditions. This type of trench machine is ordinarily confined to a length of about 300 ft., so that it is not practicable to lay long lengths of pipe at one time, as is usually done. Under some conditions, the use of this type of machine may be very desirable as making it possible to avoid throwing the dirt out on to one side of and blocking the street. Many times it is possible in this way to keep the street open to traffic, whereas if the earth were thrown out as usual, the street could hardly be kept open.

The types of trenching machine which are more commonly

* Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

used in the Middle West, where the excavating is done by some sort of a bucket elevator, are not often adapted to work in our eastern city streets, on account of the cross pipes encountered and the bracing which is required where the ground has been dug up over and over again. That machine is good for use in earth where the banks remain in position without sheeting and bracing, and where it can proceed without interfering with pipes crossing the trench.

The advantage of some types of machine, like the Carson machine, is that the earth is handled only once, simply being shoveled into a bucket, raised and carried back and dumped on to the completed work. There is, however, as I have said, great difficulty in handling water-pipe work in that way. The types of machines that are used for excavating by means of the bucket elevator in moderately compact or tenacious material can be worked very cheaply, as in many cases the earth is thrown out on to the side of the street and then it is hauled back by means of scrapers. That scheme is used a good deal in the Middle West, where the material is of a loamy nature and is not subject to caving.

Mr. Frank L. Fuller.* Mr. President, I have had two water-works jobs the past summer, one with about 60 cu. yd. of rock excavation in about six miles of trenching; the other with 488 cu. yd. in about $2\frac{1}{2}$ miles. Where there is as much rock as there was in the second case, trenching machines would not be practicable, I think. It seems to me that in New England there is too much rock to permit any saving in making the excavation by machinery, and that getting the material out by pick and shovel will be the cheaper way.

Mr. C. E. Davis.† In laying about six miles of 12- and 16-in. water pipe in Philadelphia, a Buckeye trenching machine has been used successfully. This machine consists essentially of a large wheel with excavating buckets on the periphery. A conveyer belt carries the earth forward and deposits it to one side of the trench. In Philadelphia it is working successfully in material which is comparatively free from bowlders and of rather a tenacious and clayey nature. Backfilling is being done by hand.

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* Civil Engineer, Boston, Mass.

† Chief Engineer, Bureau of Water, Philadelphia, Pa.

PROCEEDINGS.

Annual Meeting.

Hotel Brunswick,
Boston, Mass., January 14, 1914.

The President, J. Waldo Smith, occupied the chair.

The following members and guests were present:

Honorary Member.

Frederic P. Stearns.

Members.

J. M. Anderson, L. M. Bancroft, F. A. Barbour, H. K. Barrows, Dexter Brackett, E. C. Brooks, James Burnie, G. A. Carpenter, J. C. Chase, J. H. Child, J. E. Conley, A. W. Cuddeback, C. E. Davis, John Doyle, L. R. Dunn, E. R. Dyer, H. P. Eddy, E. D. Eldredge, J. W. Ellis, F. L. Fuller. Patrick Gear, F. J. Gifford, A. S. Glover, J. M. Gooding, F. W. Gow, F. M. Griswold, R. A. Hale, R. K. Hale, F. E. Hall, J. O. Hall, M. F. Hicks, J. L. Howard, A. C. Howes, F. T. Kemble, Willard Kent, J. J. Kirkpatrick, C. F. Knowlton, H. O. Lacount, E. J. Lonergan, Daniel MacDonald, F. E. McInnes, J. N. McKernan, F. E. Merrill, H. A. Miller, F. L. Northrop, S. H. Pitcher, P. R. Sanders, W. J. Sando, J. E. Sheldon, C. W. Sherman, J. W. Smith, G. H. Snell, W. F. Sullivan, R. J. Thomas, L. D. Thorpe, J. L. Tighe, C. H. Tuttle, F. E. Tupper, J. H. Walsh, R. S. Weston, T. H. Wiggin, I. S. Wood, L. C. Wright. — 63.

Associates.

Builders Iron Foundry, by A. B. Coulters; Chapman Valve Manufacturing Company, by J. J. Hartigan and J. F. Mulgrew; *Engineering Record*, by I. S. Holbrook; Hersey Manufacturing Company, by A. S. Glover and W. A. Hersey; Kennedy Valve Company, by M. J. Brosman; Lead-Lined Iron Pipe Company, by T. W. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor and G. A. Miller; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by H. L. Weston; Neptune Meter Company, by H. H. Kinsey; Rensselaer Valve Company, by C. L. Brown; A. P. Smith Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Thomson

Meter Company, by E. M. Shedd; Union Water Meter Company, by F. E. Hall; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison. — 21.

Guests.

Mr. Joseph A. Hoy, Worcester, Mass.; Charles W. Kinney and Albert H. Tillson, Northampton, Mass., F. M. Bates and C. DeWitt Webb, Boston, Mass.; D. J. Higgins, Waltham, Mass.; F. I. Hall, Middletown, Conn.; C. T. Hall, Malden, Mass., and J. H. Carmichael, Lowell, Mass. — 9.

The Secretary presented applications for active membership, properly endorsed and recommended by the Executive Committee, from Rufus M. Whittet, Boston, Mass., assistant engineer Massachusetts State Board of Health; C. C. Covert, Albany, N. Y., district engineer United States Geological Survey, Water Resources for New York and New England; Joseph A. Hoy, Worcester, Mass., foreman of construction works and service pipes in streets; Charles W. Kinney, Northampton, Mass., president Northampton Water Works; Albert H. Tillson, Northampton, Mass., supervisor of water works; Robert R. Livingston, N. Y., engaged in hydro-electric engineering and construction; and for associate membership, Daniel J. Higgins, Waltham, Mass., manufacturer of steam pumps and valves.

On motion of Mr. Frank L. Fuller, the Secretary was instructed to cast the ballot of the Association in favor of the applicants, and he having done so they were declared duly elected members of the Association.

The Secretary, Mr. Willard Kent, then presented his annual report, as follows:

Report of the Secretary.

Narragansett Pier, R. I., January 1, 1914.

Mr. President and Gentlemen of the New England Water Works Association,— The Secretary submits herewith the following detailed statement of the changes in membership for the past year.

The present membership is	758
That of one year ago was	731
A gain for the year of	27

Your constitution specifies that the membership shall consist of members, honorary members, and associates.

In the list of honorary members there has been no change, the present number being 12, the same as that of one year ago.

The changes in the list of members and associates are as follows:

MEMBERSHIP.

January 1, 1914.	Honorary members				12
January 1, 1913.	Total members		666		
	Withdrawals:				
	Resigned	17			
	Dropped	27			
	Died	7			
		—	51		
			—	615	
	Initiations:				
	January	6			
	February	1			
	March	10			
	June	5			
	September	19			
	November	5			
	December	5			
		—	51		
	Members elected in 1912, but qualified in 1913		2		
	Reinstated:				
	Member dropped, '10	1			
	Member resigned, '10	1			
	Member dropped, '12	1			
	Members dropped, '13	15			
		—	18	71	
			—	—	686
January 1, 1913.	Total associates	53			
	Withdrawals:				
	Dropped	1	1		
		—		52	
	Initiations:				
	September			8	
				—	60
January 1, 1914.	Total membership				758

NEW ENGLAND WATER WORKS ASSOCIATION.

Year.	President.	Membership at End of Year.				Annual Convention.		Receipts.	Expenditures.	Cash Balance.
		Members.	Associate.	Honorary.	Total.	Place.	Date.			
1882	(Organized)	27	—	—	27	Boston, Mass.	June 21, '82			
1882–3	*James W. Lyon	37	6	—	43	Worcester, Mass.	June 21, '83	$245.00	$87.86	$157.14
1883–4	Frank E. Hall	48	9	—	57	Lowell, Mass.	June 19–20, '84	156.14	171.90	141.38
1884–5	*George A. Ellis	83	44	—	127	Springfield, Mass.	June 18–19, '85	651.84	511.44	281.78
1885–6	*R. C. P. Coggeshall	106	47	—	153	New Bedford, Mass.	June 16–18, '86	1 658.50	1 643.42	296.86
1886–7	*Henry W. Rogers	137	52	2	191	Manchester, N. H.	June 15–17, '87	1 342.28	1 066.98	572.16
1887–8	*Edwin Darling	181	54	3	238	Providence, R. I.	June 13–15, '88	2 013.30	1 697.15	888.31
1888–9	*Hiram Nevons	209	64	4	277	Fall River, Mass.	June 12–14, '89	2 204.07	2 127.70	964.68
1889–90	Dexter Brackett	257	73	5	335	Portland, Me.	June 11–13, '90	2 511.27	2 346.65	1 129.30
1890–1	*Albert F. Noyes	281	74	5	360	Hartford, Conn.	June 10–12, '91	3 055.13	1 884.78	2 299.65
1891–2	Horace G. Holden	290	70	5	365	Holyoke, Mass.	June 8–10, '92	2 887.17	3 278.54	1 908.28
1892–3	*George F. Chace	338	69	5	412	Worcester, Mass.	June 14–16, '93	3 422.61	3 317.22	2 013.67
1893–4	*Geo. E. Batchelder	365	73	5	443	Boston, Mass.	June 14–16, '94	3 208.85	3 259.07	1 963.45
1894–5	George A. Stacy	401	81	5	487	Burlington, Vt.	Sept. 11–13, '95	3 147.41	3 115.99	2 673.03
1895–6	Desmond FitzGerald	442	82	5	529	Lynn, Mass.	June 10–12, '96	3 179.91	3 148.49	2 704.45
1896–7	*John C. Haskell	464	80	5	549	Newport, R. I.	Sept. 8–10, '97	3 340.23	3 322.94	2 271.74
1897–8	Willard Kent	488	77	5	570	Portsmouth, N. H.	Sept. 14–16, '98	3 002.13	2 786.95	2 936.92
1898–9	Fayette F. Forbes	494	73	5	572	Syracuse, N. Y.	Sept. 13–15, '99	2 825.71	3 050.23	2 712.40
1899–1900	Byron I. Cook	519	70	5	594	Rutland, Vt.	Sept. 19–20, '00	4 920.49	5 524.65	2 108.24
1901	Frank H. Crandall	493	58	4	555	Portland, Me.	Sept. 18–20, '01	4 238.55	4 283.22	2 063.57
1902	Frank E. Merrill	522	60	5	587	Boston, Mass.	Sept. 10–12, '02	5 158.48	4 680.32	2 541.73
1903	*Charles K. Walker	520	55	3	586	Montreal, Canada	Sept. 9–11, '03	5 032.40	4 505.08	3 069.05
1904	Edwin C. Brooks	538	58	8	604	Holyoke, Mass.	Sept. 14–16, '04	5 328.31	5 528.21	2 869.15
1905	George Bowers	584	53	8	645	New York, N. Y.	Sept. 13–16, '05	5 431.16	5 411.58	2 888.73
1906	Wm. T. Sedgwick	618	51	15	684	White Mts., N. H.	Sept. 12–14, '06	5 366.94	4 845.14	3 410.53
1907	John C. Whitney	636	51	15	692	Springfield, Mass.	Sept. 11–13, '07	5 291.83	†4 222.06	4 480.30
1908	Alfred E. Martin	633	49	14	696	Atlantic City, N. J.	Sept. 23–25, '08	5 706.36	7 475.56	‡2 711.10
1909	Robert J. Thomas	647	55	13	715	New York, N. Y.	Sept. 8–10, '09	5 305.31	†4 566.84	‡3 449.57
1910	George A. King	678	56	13	747	Rochester, N. Y.	Sept. 21–23, '10	6 507.08	†7 237.60	‡2 719.05
1911	Allen Hazen	680	58	12	750	Gloucester, Mass.	Sept. 13–15, '11	6 440.90	†6 279.72	‡2 880.23
1912	Geo. W. Batchelder	666	53	12	731	Washington, D. C.	Sept. 18–20, '12	6 861.65	†5 934.56	‡3 807.32
1913	J. Waldo Smith	686	60	12	758	Philadelphia, Pa.	Sept. 10–12, '13	6 122.81	†6 533.62	‡3 396.51

* Deceased. † Not including December Journal and Reprints. ‡ Does not include $1 815 invested in bond

The Secretary has received and paid to the Treasurer			$5 909.18
Of this amount the			
Receipts for initiation fees were			$281.00
From dues of members	$2 037.00		
,, ,, ,, ,, fractional	38.00		
,, ,, ,, ,, part	9.50		
		$2 084.50	
From dues of associates	$770.00		
,, ,, ,, ,, fractional	61.25	831.25	
Total from dues			2 915.75
From advertising			1 371.25
,, subscriptions			258.00
,, JOURNALS			148.50
,, sundries			934.68
Total as above			$5 909.18

There is due the Association at this date —	
For advertising	$422.50
,, JOURNALS	54.50
Total amount due	$477.00

The outstanding bills against the Association amount to $876.53.

Respectfully submitted,

WILLARD KENT, *Secretary.*

On motion of Mr. Frederic P. Stearns, it was voted that the report of the Secretary be received and placed on file.

The Treasurer, Mr. Lewis M. Bancroft, submitted the following report:

CLASSIFICATION OF RECEIPTS AND EXPENDITURES.

Receipts.

Dividends and interest		$221.01
Initiation fees	$281.00	
Dues	2 915.75	
Total received from members		3 196.75
Amount carried forward		$3 417.76

Amount brought forward		$3 117.76
JOURNAL:		
Advertisements	$1 371.25	
Subscriptions	258.00	
Sale of JOURNALS	148.50	
Sale of Reprints	31.50	
Total received from JOURNAL		1 809.25
Miscellaneous receipts:		
Sale of " Pipe Specifications "	$31.30	
Dinners	670.50	
June excursion	194.00	
Total miscellaneous receipts		895.80
Total receipts		$6 122.81

Expenditures.

JOURNAL:		
Advertising agent, commission	$242.00	
Plates	318.12	
Printing	1 638.30	
Editor's salary	300.00	
Expense	37.36	
Reporting	141.00	
Advance reports	168.71	
Reprints	190.25	
Envelopes	57.00	
		$3 092.74
Office:		
Secretary, salary	$200.00	
Expense	32.50	
Assistant Secretary, salary	600.00	
Expense	164.55	
Rent	300.00	
Printing	116.00	
Stationery	48.00	
Membership lists	199.00	
Envelopes and postage	123.04	
Typewriter	95.00	
Library	13.55	
Miscellaneous	20.50	
		1 912.14
Amount carried forward		$5 004.88

Amount brought forward			$5 004.88
Meetings and Committees:			
Stereopticon		$71.50	
Dinners	$689.00		
Cigars	48.50		
Music	79.00		
		816.50	
Badges		78.14	
Printing and postage		150.35	
			1 116.49
Treasurer's salary and bond			67.50
June excursion			317.25
Printing Pipe Specifications			27.50
			$6 533.62

LEWIS M. BANCROFT, TREASURER,

In account with the New England Water Works Association.

RECEIPTS.			EXPENDITURES.		
1913.					
Jan. 1.	Balance on hand	$3 807.32	Bills paid		$6 533.62
	Received of Willard Kent, Sec'y	5 909.18	BALANCE ON HAND.		
	Interest on bonds and deposits	213.63	People's Savings Bank	$2 000.00	
			Mechanics Savings Bank	1 055.96	
			First National Bank	292.83	
			Liberty Trust Co.	47.72	
					3 396.51
		$9 930.13			$9 930.13

ASSETS AND LIABILITIES.

ASSETS.			LIABILITIES.	
Cash, balance in banks		$3 396.51	Accounts payable:	
Bonds Nos. 2642 and 2644 Lake Shore & Mich. So. R. R. 4%, due May 1, 1931. Book value, $1 815. Market value		1 800.00	Rent	$100.00
			Reporting	26.25
Accounts receivable:			Miscellaneous Printing	81.13
JOURNALS	$55.50		Printing	655.40
Advertising	422.50		Asst. Sec'y, Expense	13.75
				$876.53
		478.00	Surplus	4 797.98
		$5 674.51		$5 674.51

READING, January 8, 1914.

LEWIS M. BANCROFT, *Treasurer.*

On motion of Mr. Edwin C. Brooks, it was voted that the report of the Treasurer be accepted and placed on file.

The Editor, Mr. Richard K. Hale, submitted the following report:

Report of the Editor.

Boston, January 14, 1914.

To the New England Water Works Association, — I present the following report for the Journal of the New England Water Works Association for the year 1913.

The accompanying tabulated statements show in detail the amount of material in the Journal; the receipts and expenditures on account of the Journal for the past year (including the cost of the December Journal and reprints, bills for which were received too late to pay in 1913, and which are consequently not included in the Treasurer's statement); and a comparison with the conditions of preceding years.

Size of Volume. — The volume is somewhat larger than in previous years.

Illustrations. — The total cost of illustrations for the year, including printing, has been $491.95, or 13.7 per cent. of the gross cost of the volume.

Reprints. — The usual fifty reprints of papers have been furnished to authors without charge, and additional reprints, when desired, at the cost of the paper and press work. The net cost to the Association for reprints has been $105.10. There have been advance copies of seven (7) papers prepared during the year, at a cost of $141.71.

Circulation. — The present circulation of the Journal is:

Members, all grades	758
Subscribers	73
Exchanges	27
Total	858

an increase of 32 over the preceding year. Journals have also been sent to 40 advertisers.

Advertisements. — There has been an average of 25 pages of paid advertising, with an income of $1,690, a slight decrease over last year.

Pipe Specifications. — During the year the specifications for cast-iron pipe to the value of $31.30 have been sold; 500 were printed at a cost of $27.50. The net gain up to a year ago had been $254.95, so that the total net gain from this source to date is $258.75. There are still about 400 copies of specifications on hand, or about $40.00 worth if sold at retail.

The Association has a credit of $2.41 at the Boston Post-Office, being the balance of the money deposited for payment of postage upon the Journal at pound rates.

There are no outstanding bills, on account of the Journal, which are not included in these tables.

Respectfully submitted,

RICHARD K. HALE, *Editor.*

TABLE No. 1.

STATEMENT OF MATERIAL IN VOLUME XXVII, JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION, 1913.

Number.	Date.	Pages of Papers.	Proceedings.	Total Text.	Membership Changes and Exchange List.	Index.	Advertisements.	Cover and Contents.	Inset Plates.	Total.	Total Cuts.
1	March	143	25	168	1	—	30	4	9	212	36
2	June	125	13	138	—	—	29	4	6	177	24
3	September	147	16	163	4	—	29	4	17	217	40
4	December	81	4	85	—	6	29	4	3	127	18
	Total	496	58	554	5	6	117	16	35	733	118

TABLE No. 2.

RECEIPTS AND EXPENDITURES ON ACCOUNT OF VOLUME XXVII, JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION, 1913.

Receipts.		*Expenditures.*	
Advertisements	$1 690.00	Printing JOURNAL . . .	$1 994.35
Sale of JOURNAL	203.00	Printing illustrations . .	228.00
Sale of reprints	109.15	Preparing illustrations .	263.95
Sale of cuts	3.24	Editor's salary	300.00
Subscriptions	258.00	Editor's incidentals . . .	38.28
		Advertising agent's commissions	237.00
	$2 263.39		
Net cost of JOURNAL . .	1 322.90	Miscellaneous printing .	1.50
		Reporting	167.25
		Reprints	214.25
		Advance copies	141.71
	$3,586.29		$3 586.29

TABLE No. 3.

COMPARISON BETWEEN VOLUMES XVIII TO XXVII, INCLUSIVE, JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION.

	VOL. XVIII. 1904.	VOL. XIX. 1905.	VOL. XX. 1906.	VOL. XXI. 1907.	VOL. XXII. 1908.	VOL. XXIII. 1909.	VOL. XXIV. 1910.	VOL. XXV. 1911.	VOL. XXVI. 1912.	VOL. XXVII. 1913.
Average edition (copies printed)	900	900	900	1 085	1 000	1 000	1 150	1 000	1 000	1 000
Average membership	596	625	665	693	699	710	732	752	710	745
Circulation at end of year	667	705	767	785	780	802	827	840	826	858
Pages of text	491	587	495	500	500	459	613	475	401	551
Pages of text per 1 000 members	824	939	715	722	715	646	880	632	542	746
Total pages, all kinds	791	781	662	669	681	627	808	651	567	733
Total pages per 1 000 members	1 332	1 251	995	964	976	881	1 090	870	766	984
GROSS COST:										
Total	$2 928.77	$3 266.65	$2 573.61	$2 613.42	$2 733.61	$3 111.15	$3 190.81	$2 625.87	$2 476.55	$3 586.29
Per page	3.69	4.17	3.88	3.95	4.01	4.97	1.32	1.02	4.37	4.89
Per member	1.91	5.23	3.87	3.82	3.91	4.39	4.78	3.50	3.35	4.81
Per member per 1 000 pages	6.18	6.67	5.85	5.70	5.88	7.00	5.90	1.09	5.90	6.46
Per member per 1 000 pp. text	10.00	8.91	7.81	7.62	8.02	9.56	7.44	7.36	8.35	8.68
NET COST:										
Total	$618.11	$1 072.95	$387.96	$483.15	$131.06	$789.98	$1 334.06	$352.82	$98.81	$1 322.90
Per page	.82	1.37	.58	.72	.19	1.26	1.65	.54	.17	1.80
Per member	1.09	1.72	.58	.70	.19	1.11	1.82	.47	.13	1.78
Per member per 1 000 pages	1.30	2.20	.88	1.04	.28	1.78	2.25	.55	.23	2.42
Per member per 1 000 pp. text	2.22	2.93	1.18	1.39	.39	2.43	2.83	.98	.33	2.38

No objection being made, the President announced that the report of the Editor would be received, placed on file and printed in the JOURNAL.

REPORT OF THE AUDITING COMMITTEE.

Mr. John C. Chase submitted the following report of the Auditing Committee:

BOSTON, MASS., January 8, 1914.

We have examined the accounts of the Secretary and Treasurer of the New England Water Works Association, and find the books correctly kept and the various expenditures of the past year supported by duly approved vouchers.

Respectfully submitted,

ALBERT L. SAWYER,
JOHN C. CHASE,
Auditing Committee.

No objection being made, the President announced that the report would be received, placed on file, and printed in the JOURNAL.

REPORT OF COMMITTEE TO PREPARE A STANDARD SPECIFICATION FOR FIRE HYDRANTS.

Mr. H. O. Lacount for the committee "to prepare a standard specification for fire hydrants," presented the following report:

TO THE NEW ENGLAND WATER WORKS ASSOCIATION:

Gentlemen,—Since the last report of your committee a joint conference has been held with representatives of the hydrant manufacturers and the hydrant committees of the American Water Works Association and the National Fire Protection Association. While the conference was unable to come to an agreement on some points, there were a number of items regarding which satisfactory conclusions were reached, and these have been incorporated in the latest revision of the specifications.

The final report of the committee is practically ready, and if agreeable to the Association it will be presented at the next meeting, in February. It is expected that, as usual, advance copies of the proposed specifications will be circulated to the members prior to the meeting, in order to facilitate the discussion when the subject comes before the Association for final consideration.

(Signed) H. O. LACOUNT,
Chairman.

The President announced that the committee would be continued and would make a final report at a later date.

The next matter on the program was the report of the committee "to look after and keep track of legislation and other matters pertaining to the conservation, development, and utilization of the natural resources of the country."

No one being present to represent the committee, the matter was passed.

Mr. Frederic P. Stearns, chairman of the committee "to collect information as to low-water yields of catchment areas in New England, and at their discretion, outside of New England," reported that the committee has made substantial progress, and although not ready at present to report, it hopes to be at an early date.

Report of Committee on Meter Rates.

The Secretary, Mr. Kent, read the following letter from Mr. Allen Hazen, chairman of the Committee on Meter Rates.

December 22, 1913.

Mr. Willard Kent,

Secretary, New England Water Works Association,

Tremont Temple, Boston, Mass.

Dear Sir, — The Committee on Meter Rates respectfully reports that it has held one full meeting, that matters referred to it have been considered by its members, that data are being obtained from members of the Association as to some matters upon which the Committee desired assistance, and that the matter will be further considered during the coming year.

Respectfully,

(Signed) Allen Hazen,
Chairman of Committee.

The President. If there is no objection the committee will be continued.

Report of Committee on Statistics of Water Purification Plants.

Mr. Robert S. Weston. Professor Whipple, being unable to be present to-day, has asked me to report for the Committee on Statistics of Water Purification Plants. The committee has held

two meetings in New York, and has prepared a large number of forms which are being sent out in sets to fifty different water purification plants in the country, with the request that the forms be criticised and the data requested on the forms be sent in to the committee. The committee had hoped to have these forms printed for distribution, but upon further consideration it was thought that it would be wiser to have them perfected before doing so; and your committee hopes to do this at a later meeting of the Association. The work is going to be rather laborious and will require a great deal of correspondence and considerable thought, and your committee asks to be continued.

THE PRESIDENT. If there is no objection, the committee will be continued and report at a later date.

REPORT OF COMMITTEE TO SECURE LEGISLATION TO MAKE WATER BILLS A LIEN ON PROPERTY.*

MR. JOHN O. HALL. *Mr. President and Gentlemen of the Association,* — In conference with Judge Corbett, of the Law Department of the City of Boston, a bill has been prepared, and he will introduce it in the legislature in season for action by the proper committee. I have sent out about seventy requests to various water companies, asking for a statement of their total revenue for the year and the amount lost by reason of change of tenants. Those reports are coming to me; I have at the present time about forty. I have seen the secretary of the Massachusetts Real Estate Exchange and have arranged to have a meeting of our committee with the legislative committee of the Exchange, as soon as the bill is presented to the legislature. We will then thresh the matter out with them and listen to their objections, and I think that without any question we can present the matter in such shape to them that they will assist us in favoring the bill before the committee.

Mr. McInnes is present to-day and he can doubtless inform the Association that the bill will be presented to the legislature in due season, and then I will call the committee together and we will confer on the information which has been secured and

* See also pp. 101, 105.

plan out our action before the legislative committee, and at a later meeting will make a final report of the result.

THE PRESIDENT. If there is no objection the committee will be continued.

REPORT OF COMMITTEE FOR STANDARD SPECIFICATION FOR CAST-IRON PIPE.

MR. F. A. MCINNES. This committee is unable to make other than a progress report at the present time. Undoubtedly we seem to be going slowly, but we feel that it is necessary to do so in order to get what we are aiming at, namely, a specification that will be a distinct advance and one which will be accepted by the great majority of those interested. One meeting has already been held this winter and one is scheduled for to-night, and next week it is hoped that at least an informal joint meeting will be held with the committee of the American Water Works Association. That, I think, expresses our present standing.

THE PRESIDENT. If there is no objection the committee will be continued. We are glad to hear that progress is being made in this very important matter. We realize, with the chairman of the committee, that delay is worth while if we can get a uniform specification that will be agreed to by most of the water-works interests.

The reports of committees having been received, subjects for topical discussion were taken up. The first was, "Methods used to Locate Hidden Leaks in Underground Pipes, with Special Reference to Pipes whose Exact Location is Unknown." The only member who spoke on this subject was Mr. Patrick Gear, of Holyoke.

The next subject was, "Are Trenching Machines Worth Considering in Excavating Trenches in City Streets?" This was discussed by Mr. Harrison P. Eddy, Mr. Frank L. Fuller, and Mr. C. E. Davis.

Then Mr. Francis T. Kemble brought up the matter of a proper charge for fire protection service. This subject was discussed by Mr. Frank E. Merrill, Mr. Charles H. Tuttle, Mr. H. O. Lacount, Mr. Robert S. Weston, Mr. Charles W. Sherman, Mr.

Patrick Gear, Mr. Robert J. Thomas, Mr. Carleton E. Davis, and Mr. John Doyle.

Mr. J. Waldo Smith, the retiring President, then made his address.

President's Address.

Gentlemen of the New England Water Works Association, — The reports which have just been read by the Secretary, the Treasurer, and the Editor have given in detail the conduct of the business of the Association during the past year. All are of an encouraging nature and show a prosperous and healthful condition. The membership shows a net gain of 27 over last year, which is gratifying, when it is considered that 1912 showed a net loss of 19. Further than this, no comments on these reports seem necessary.

This Association has always been noted for the excellence of the work of its special committees, which is disclosed in reports presented from time to time. Progress reports of four committees have been presented during the past year, as follows: Standard Specifications for Cast-Iron Pipe; Standard Specifications for Fire Hydrants; To Look After and Keep Track of Legislation and Other Matters Pertaining to the Conservation, Development, and Utilization of the Natural Resources of the Country; To Collect Information as to Low Water Yields of Catchment Areas in New England, and, at Their Discretion, Outside of New England. The final report of the Committee on Water Consumption and Statistics relating thereto has also been presented, and it forms a most valuable and important addition to the work done by this Association. During the year two new special committees have been appointed, on meter rates and on uniform methods of reporting operation of filtration plants. Both are important subjects which have long needed attention.

The larger engineering societies and associations of a similar technical nature and having national or even international scope are coming to recognize that their growth in influence and ability to benefit their members must largely be along the lines of recommendations and reports by select committees. Considering its size and territorial limits, the New England Water Works Association can justly claim to have been a leader. Its committees

have been made up of skillful men, experienced in the particular line of research required, who have been willing to sacrifice valuable time and even money in making the necessary studies. The difficulties of committee work arise from the fact that most men, and particularly those who are suitable committee members, are almost constantly busily occupied with their regular duties. A water-works superintendent must be a very versatile man. He must, first of all, be an engineer, using the term in its broad and not in its technical sense. He must also be something of a lawyer, an accountant, a bookkeeper, a resourceful mechanic, and a diplomat, and naturally, as a result, his time is very fully occupied in performing these many functions of his position. The engineer engaged in consulting or construction work has many and varied obligations of which he must acquit himself, and so his time, too, is only to a limited extent his own. When all of these conditions are considered and it is remembered that in nearly every case these excellent reports have been the product of the "midnight oil," this Association is indeed to be congratulated on the high quality of the work which has been performed by its committees.

Even with a high-class committee, successful work is possible only through the cordial coöperation and assistance of the general membership of the Association. The speaker has, himself, experienced great difficulty in gathering definite and reliable information on various subjects. The reports and replies received in response to letters asking for information are most often indefinite and misleading. Thus, for example, the answers to an inquiry concerning the satisfaction which has been given by some automatic device in general use in connection with water supplies will reveal a most astounding condition of affairs. Many will report "perfect performance" and many will say that the device is of absolutely "no use." In this connection the speaker is reminded of the story of the two men who were discussing the laundry question. One complained that he had no end of trouble and the other that he always got perfect service. It developed, however, in discussion, that the "no trouble" man never counted the pieces he sent to be laundered! There are many, in all walks of life, who shut their eyes to trouble in a similar manner, and no

exception can be made of the water-works engineer. The speaker is convinced, from what he has observed, that many devices and appliances used on water systems are accepted on faith and are never put through a practical test to determine their efficiency and reliability in the situations where they are to be used. These devices after installation are seldom examined, and so it is never known whether they perform their intended function either perfectly or not at all. It thus comes to pass that the man who never looks for trouble is the one most likely to make erroneous and misleading reports.

This Association is essentially one of water-works superintendents — hard-headed practical men of good judgment — resourceful and adaptable. To aid them in their work of construction and management of water-works plants have come the engineers. Both classes are necessary for success, and there should be, wherever the best results are to be obtained, the most cordial coöperation. The ability to coöperate must also exist between engineer and contractor, between the superintendent and his men and between the rank and file of the working force. The more perfect the coöperation, the more noiselessly, efficiently, and economically the machine will run. This spirit of working hand in hand for the furtherance of the job is the keynote of the success of every work or enterprise. It is the foundation on which is built the attainment of the best results, in the quickest time and for the least expenditure. Fair dealing, harmony, and honest coöperation do more to oil the wheels of progress than all other known factors and result in the highest credit for the superintendent, for the engineer, for the contractor and for every man on the work. But coöperation and unity of thought cannot be had without some sacrifice on the part of every individual who may be charged with any degree of responsibility. The superintendent must often subordinate his views to those of his foreman, so that they, in turn, may fully understand and share with him the satisfaction and joy of attainment and successful accomplishment. The engineer must often accept the ideas of his inspectors, for, if he does not, whence can their lively and healthful interest in the work be expected to come? It matters little by just what method a thing is done, but it matters much, indeed, that the

thing when done shall be as perfect as possible and properly perform its intended function. All of us are often too prone to stick close to our own ideas and defend them to the bitter end of ignominious failure, and some, even in failure, learn not! The yielding of an immaterial point, or often one which for the moment seems most vital, is one of the surest ways in which coöperation can be induced among individuals and by which unswerving loyalty to a work, to a project, or to a cause can, in the first place, be induced, and, in the second, held immovably fast. But subordination of one's own pet ideas and theories is not of itself all sufficient, unless proper credit is given for that plan which is finally adopted and unless due recognition of individual merit and ability is freely and honestly given.

The financial rewards of those in charge of water-works systems are very small when the great responsibility is considered and when it is remembered that success is to be obtained only as the result of continual vigilance and never-failing fidelity. But it so happens, fortunately indeed, that those endowed with most of this world's goods are not the happiest and that the realization of a duty well performed is of itself the highest of rewards. No greater joy can come to any one than that resulting from his associations and his accomplishments. Both of these are within the reach of every one, and I am sure that by the large majority of you they have already been attained and are among the choicest of your possessions.

In these days of unrest among all classes and conditions of men, and particularly among those high in the councils of our governing political bodies, it is indeed a pleasure, and none the less my duty, to bear witness to the unswerving honesty, fidelity, and loyalty which has as a class always characterized the water-works man and the engineer. It is my earnest hope that they will see their way clear to look beyond their immediate duties and the responsibilities of their environment, and take a greater interest and exert a real and more marked influence on the many and complex problems which our urban development has forced upon us. The man of technical training and possessing all of the qualifications and characteristics which the water-works man must of necessity be endowed with is the one, after all, who is best

fitted to further and progress any work or movement he may undertake. It is necessary only for him to put his shoulder to the wheel and make up his mind to take the same active part in the affairs of his city as that which he has played in the water department. Having once taken the plunge, he will find awaiting him the same measure of success and he will wonder why he was so long content to see the reward and the credit go to others who deserved it less; yes, indeed, to many who deserved it not at all!

But, as we seek to widen our field of activity, let us steadfastly refuse to follow the easy and now popular style of advancement through carping and destructive criticism. All can criticise, but few can raise up; let us be builders and not tearers down! Let us take what may be justly criticised and improve and make the best of it, rather than to uproot it stem and branch, only to cast it down to destruction. Let us take the constructive side and, in so doing, play our part in helping to make this world better, brighter, and more livable. But withal, let us subordinate our desires and ambitions of personal aggrandizement so that whatever we may do and accomplish will pay its own reward in that sense and feeling of satisfaction which ever comes to those who, in doing a good work, do it well.

Let us ever do the tasks which come to us with honesty and with fidelity of purpose, so that wherever or whenever our time of trial may come, we can boldly and without fear look the whole world in the face and bid any and every member of society to come on and do his worst.

Report of Tellers.

The tellers appointed to canvass the ballots for officers for the coming year submitted the following report:

Election of Officers.

Whole number of ballots	275
Blank	9

President.

Frank A. McInnes	262
Scattering	1

Vice-President.

Leonard Metcalf	272	James W. Blackmer	267
William F. Sullivan	268	Charles E. Chandler	265
Carleton E. Davis	267	Scattering	2
Melville A. Sinclair	265		

Secretary.

Willard Kent 273

Treasurer.

Lewis M. Bancroft 268

Editor.

Richard K. Hale 268

Advertising Agent.

George A. King 264
Scattering 1

Additional Members of Executive Committee.

Robert J. Thomas 265
Samuel E. Killam 263
Samuel P. Senior 263
Scattering 1

Finance Committee.

George H. Finneran 263
A. R. Hathaway 265
Frederick W. Gow 271
Scattering 2

Respectfully submitted,

F. M. GRISWOLD.
A. C. HOWES.
S. H. PITCHER.

Mr. J. Waldo Smith. It is now my duty and pleasure to hand over this gavel to my distinguished successor, Mr. McInnes, and to introduce him, if he needs any introduction, to the New England Water Works Association. [*Applause.*]

President McInnes. Gentlemen, this is my first experience at this table, and, if I tell the whole truth, I am at this moment very envious of you gentlemen who are sitting in front of me. However, it is your will and it is my duty, and it shall be my en-

deavor to justify your choice. Your very kind applause was sweet music, for it gives me reason to hope that for the coming year the past high standards of the Association may be maintained, for without your coöperation I fully realize that nothing worth while can be done. I sincerely thank you for the great honor you have done me. [*Applause.*]

Adjourned.

February Meeting.

Hotel Brunswick,
Boston, February 11, 1914.

The President, Mr. Frank A. McInnes, in the chair.

The following members and guests were present:

Members.

A. F. Ballou, L. M. Bancroft, F. A. Barbour, A. E. Blackmer, J. W. Blackmer, George Bowers, James Burnie, G. A. Carpenter, George Cassell, J. C. Chase, R. D. Chase, R. C. P. Coggeshall, C. H. Eglee, E. D. Eldredge, G. F. Evans, G. H. Finneran, F. F. Forbes, R. V. French, A. D. Fuller, F. L. Fuller, Patrick Gear, A. S. Glover, Clarence Goldsmith, R. A. Hale, R. K. Hale, F. E. Hall, J. O. Hall, L. M. Hastings, A. R. Hathaway, Allen Hazen, D. J. Higgins, H. R. Johnson, W. S. Johnson, E. W. Kent, Willard Kent, G. A. King, F. F. Longley, F. A. McInnes, Thomas McKenzie, W. E. Maybury, John Mayo, H. A. Miller, William Naylor, T. A. Peirce, L. C. Robinson, P. R. Sanders, A. L. Sawyer, C. W. Sherman, G. A. Stacy, W. F. Sullivan, C. N. Taylor, L. D. Thorpe, E. J. Titcomb, D. N. Tower, C. H. Tuttle, F. E. Tupper, A. H. Tillson, W. H. Vaughn, Percy Warren, F. P. Washburn, R. S. Weston, H. L. Whitney, F. B. Wilkins, F. I. Winslow, G. E. Winslow, I. S. Wood, and L. C. Wright. — 68.

Associates.

Chapman Valve Manufacturing Company, by H. U. Starr and J. F. Mulgrew; Goulds Manufacturing Company, by R. E. Hall; Joseph Dixon Crucible Company, by H. A. Neally; Hersey Manufacturing Company, by A. S. Glover and W. A. Hersey; Lead Lined Iron Pipe Company, by T. W. Dwyer; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; Neptune Meter Company, by H. H. Kinsey; Norwood Engineering Company, by R. B. Weir; Pitometer Company, by E. D. Case; Pittsburg Meter Company, by J. N. Turner; Pratt & Cady Company, by C. E. Pratt; Rensselaer Valve Company, by C. L. Brown; Standard Cast Iron Pipe and Foundry Company, by W. F. Woodburn; Thomson Meter Company, by E. M. Shedd; Union Water Meter Company, by F. E.

Hall; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by C. R. Wood; Henry R. Worthington by Samuel Harrison, E. P. Howard, and W. F. Bird. — 24.

GUESTS.

C. C. Young, Lawrence, Kan.; Frank F. Street, A. J. Brown, Reading, Mass.; James Kinloch, East Greenwich, R. I.; George W. Bowers, Lowell, Mass.; S. W. Hume, New York; S. L. Hildreth, Manchester, Mass.; C. A. Abbott, Derry, N. H.; Prof. S. C. Prescott, Boston; Joseph Weeks, Bridgewater, Mass.; R. F. Forrest, Randolph, Mass.; E. E. Abercrombie, Beverly, Mass.; E. H. Magoon, Almon L. Fales, Boston, Mass.; H. H. Ambler, T. P. Hsi, Z. Y. Chow, E. W. Bowles, C. J. Callahan, E. D. Hayward, E. C. Taylor, and S. Brack. — 22.

The Secretary presented the application for membership, properly endorsed and recommended by the Executive Committee, of C. C. Young, Lawrence, Kan., director of the Kansas State Water Survey. On motion of Mr. T. A. Peirce, the Secretary was instructed to cast the ballot of the Association in favor of the applicant, and he having done so Mr. Young was declared duly elected an active member of the Association.

The Secretary read the following letter and report from Mr. M. N. Baker, chairman of the committee "to look after and keep track of legislation and other matters pertaining to the conservation, development, and utilization of the natural resources of the country."

NEW YORK, January 13, 1914.

MR. WILLARD KENT,

Secretary, New England Water Works Association,

TREMONT TEMPLE, BOSTON, MASS.

Dear Mr. Kent, — I regret to say that I will be unable to be at the meeting to-morrow. I enclose a "progress" report for the Conservation Committee.

Yours truly,

M. N. BAKER.

Report of Committee to Look After and Keep Track of Legislation and Other Matters pertaining to the Conservation, Development, and Utilization of the Natural Resources of the Country.

The committee as a whole has no report to submit. The chairman begs to suggest that there seems to be little for the committee to do, and that the committee might be discharged without loss to the Association. In case the Association wishes to continue the committee, the chairman respectfully suggests that its long and cumbersome title be changed to read "Committee on Conservation."

Respectfully submitted,

M. N. Baker, *Chairman.*

On motion of Mr. Sherman, it was voted that the report of the committee be accepted and the committee discharged.

Report of Committee to Secure Legislation to Make Water Bills a Lien on Property.*

Mr. John O. Hall. The committee to which was assigned the matter of trying to secure legislation to make unpaid water bills a lien on the estate beg leave to report progress. At the present time we are apparently licked, but we do not propose to stay licked if we can help it. The bills were properly filed, and a hearing was assigned for January 26. Your committee got busy and got out all the notices that they could to various members of the Association. We appeared before the committee, some few of us, and stated our position in regard to the matter, but the committee reported leave to withdraw. That report was accepted on February 5, I think. Now, in connection with the President and Mr. Sullivan, we propose to see if there is not any parliamentary action we can take to revive the situation this year and bring the bill up again.

Mr. Robert Spurr Weston, consulting sanitary engineer, Boston, Mass., presented a paper entitled, "Some Recent Experiences in the Deferrization and Demanganization of Water."

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* See also pp. 91, 105.

He prefaced the reading of the paper by numerous experiments illustrating his subject, and at the conclusion of the paper further illustrated his work by a series of lantern slides. The paper was discussed by Mr. F. F. Forbes and Mr. Allen Hazen.

THE PRESIDENT. My ambition, gentlemen, is, as doubtless has been that of all the presidents before me, to make these meetings as interesting as they can possibly be made. Now, one thing which has been borne in on my mind very strongly indeed, is, that the practical men — I mean by that the men who spend all of their time in the actual work of operating water works, practical water-works men — have not been in evidence as much as they should have been, in the last few years, for the best interests of all of us. They were wise enough to found this Association and to bring it to a high plane practically unaided, and I am convinced that they are wise enough now to give the Association a great deal more of value than they have given it in the last few years, since I have been a member. Sometimes very homely things are also very valuable things, and somehow or other I want to see if I can't get you to tell us some of those things, so that we all may know them and may have the advantage of them. So what I have in mind is that we may have something that may be termed a practical half hour, during which the superintendents and managers, the men who all day long work and think in connection with our various problems, can tell us whatever of interest and whatever of value may have occurred to them.

MR. STACY. Mr. President, I want to say a word about another matter. I understand that it is a settled fact, that we are going to have our next annual convention in Boston. That being so, I think it is well for us to consider making a special effort so that it may be the banner convention. Boston is the headquarters of this Association, and there are attractions enough here and in this vicinity to entertain the world, and I hope an effort will be made to make the next annual convention better than any that we have ever had, worthy of the city and worthy of the Association.

MR. W. S. JOHNSON. It may be of interest in connection with what Mr. Stacy has just said to know that during the last winter, when I have been trying to get some statistics with regard to the

small water-works systems in Massachusetts, I have found that out of 113 different towns, only 15 are represented in this society. That is, of 113 water-works systems in Massachusetts, small water-works systems, there are nearly one hundred which have no representative here. Now, it seems to me this is a thing which ought not to be. The superintendent of a small water works needs this Association a good deal more than the superintendent of a large system, and we need him also. I think in many cases the superintendents would be glad to be members of the Association, — I have found it so when I have approached them, — but they haven't had their attention called to us. It seems to me that in connection with the next annual convention would be a good time to get in some of these men who are running the smaller plants.

Mr. Caldwell. Along that line, Mr. President, of getting the superintendents of the small works in, I have talked that a good deal myself when I have come in contact with them, and I have found that the majority of them would like to become members of the Association. But there is one thing that stands in their way, and that is that they are paid such small salaries that they don't feel that they can stand the expense. It seems to me that if this matter could be brought before the water boards and put up to them in the right light, they might be willing to pay the dues for their superintendents to become members of the Association. You can't blame a man who is getting may be fifty dollars a month and having to live on that, for not becoming a member of the Association and having to pay his own expenses. I make this as a suggestion, that you send out a circular letter to the water boards, calling attention to the fact that it would be for their interest more than for the interest of the superintendents themselves, to have them become members of the Association.

The President. These remarks are particularly interesting to me, because it seems almost self-evident that there never has been a year when it has been so very desirable, in fact almost imperative, that we should largely increase our membership. It seems to be a necessity this year, and I am very glad to have heard the remarks on this line.

Adjourned.

Hotel Brunswick,
Boston, Mass., March 11, 1914.

President Frank A. McInnes in the chair.

The following members and guests were present:

Honorary Member.

Desmond FitzGerald.

Members.

A. F. Ballou, L. M. Bancroft, F. A. Barbour, A. E. Blackmer, J. W. Blackmer, E. M. Blake, Dexter Brackett, E. C. Brooks, W. L. Butcher, G. A. Carpenter, F. H. Carter, J. C. Chase, R. D. Chase, J. H. Child, W. R. Conard, J. H. Cook, J. A. Cushman, J. M. Diven, A. O. Doane, E. D. Eldredge, G. F. Evans, F. F. Forbes, E. V. French, F. L. Fuller, Patrick Gear, A. S. Glover, Clarence Goldsmith, J. M. Goodell, F. W. Gow, F. H. Gunther, R. A. Hale, R. K. Hale, F. E. Hall, J. O. Hall, H. A. Hanscom, A. R. Hathaway, T. G. Hazard, Jr., D. A. Heffernan, A. C. Howes, H. R. Johnson, W. S. Johnson, E. W. Kent, Willard Kent, Patrick Kieran, G. A. King, Morris Knowles, H. O. Lacount, F. A. McInnes, S. H. McKenzie, Thomas McKenzie, W. A. McKenzie, J. N. McKernan, W. E. Maybury, John Mayo, J. H. Mendell, F. E. Merrill, H. A. Miller, William Naylor, Henry Newhall, F. L. Northrop, R. W. Parlin, T. A. Peirce, H. E. Perry, Dwight Porter, L. C. Robinson, P. R. Sanders, A. L. Sawyer, J. E. Sheldon, C. W. Sherman, Sidney Smith, G. A. Stacy, W. F. Sullivan, H. A. Symonds, H. L. Thomas, R. J. Thomas, L. D. Thorpe, J. A. Tilden, A. H. Tillson, E. J. Titcomb, D. N. Tower, C. H. Tuttle, F. E. Tupper, W. H. Vaughn, G. E. Winslow, I. S. Wood, and L. C. Wright. — 86.

Associates.

Allen & Reed, Inc., by Z. M. Jencks; Builders Iron Foundry, by A. B. Coulters; Chapman Valve Manufacturing Company, by J. J. Hartigan, C. E. Pratt, Robert Shirley, J. F. Mulgrew, and A. C. Pilcher; Darling Pump and Manufacturing Company, Limited, by H. A. Snyder and J. L. Hough; Eddy Valve Company, by John Knickerbocker; Hersey Manufacturing Company, by A. S. Glover, J. A. Tilden, and W. A. Hersey; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by J. K. Caldwell and A. R. Taylor; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; National Water Main Cleaning Company, by B. B. Hodgman; Neptune Meter Company, by H. H. Kinsey; Norwood Engineering Company, by H. W. Hosford; Pitometer Company, by E. D. Case; Pittsburgh Meter Company, by J. W. Turner; Rensselaer Valve Manufacturing Company, by C. L. Brown; A. P. Smith Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Thomson Meter

Company, by S. D. Higley and E. M. Shedd; Union Water Meter Company, by F. E. Hall; United States Cast-Iron Pipe and Foundry Company, by W. G. Sackett; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; and Henry R. Worthington, by Samuel Harrison and E. P. Howard. — 35.

GUESTS.

John Damon, water commissioner, Plymouth, Mass.; C. B. Parker, Melrose, Mass.; F. S. Lovewell, Providence, R. I.; Z. R. Forbes, water registrar, Brookline, Mass.; Edward Lotz, assistant superintendent, Southington, Conn.; Fred Darling, superintendent water works, Franklin, Mass.; H. A. Rowell, engineer, Concord, N. H.; J. G. Whitman, superintendent water works, Quincy, Mass.; Thos. E. Irwin, New York, N. Y.; R. A. Thayer, engineer, Lockwood Company; J. P. Wentworth, and W. O. Teague, engineer Factory Mutual Company, Boston, Mass. — 12.

The Secretary presented the following applications for membership, properly endorsed and recommended by the Executive Committee: Patrick J. Lucey, Holyoke, Mass., engineer of the Holyoke Water Works; Almon L. Fales, Worcester, Mass., formerly chemist in charge of the laboratories at Worcester City Hall and the sewerage works and superintendent of the works, and now of the firm of Metcalf & Eddy; William H. Butler, Wakefield, Mass., superintendent water works.

On motion of Mr. Thomas A. Pierce, the Secretary was directed to cast the ballot of the Association in favor of the applicants, and he having done so, they were declared duly elected members of the Association.

Mr. John O. Hall, for the committee on the matter of securing legislation making water bills a lien on real estate, submitted the following report: *

BOSTON, MASS., February 11, 1914.

NEW ENGLAND WATER WORKS ASSOCIATION, in Session:

Mr. President and Gentlemen, — Your committee to whom was assigned the matter of securing legislation making water bills a lien on real estate have attended to that duty and beg leave to report as follows:

A bill, copy of which is attached hereto, was introduced in the legislature, and the matter was presented before the Joint Committee on Judiciary at a hearing on January 26.

On that bill the committee reported "leave to withdraw," and the report

* See also pp. 91, 101, 105.

has been accepted by both the House and Senate, and the matter is killed for this year.

The chairman of your committee interviewed the Senate chairman of the committee and he informed me that they reached their decision on the ground of making extra labor in the examination of conveyances.

He stated to me that the amounts lost in the different cities and towns was very small compared to the amount of the annual water bills.

Your committee received returns from 48 cities and towns. The information contained in those returns is appended hereto.

Respectfully submitted,

JOHN O. HALL,
A. R. HATHAWAY,
GEORGE A. KING,
Committee.

EXHIBIT A.

TABLE SHOWING THE TOTAL COLLECTIONS OF WATER RATES AND THE AMOUNTS UNCOLLECTIBLE.

	Total Collections.	Amount Uncollectible.
Onset	$9 500.00	$308.00
Quincy	122 000.00	734.99
Wellesley Hills	25 598.00	20.70
Manchester	19 420.44	76.15
Gardner	62 688.72	219.04
Gloucester	108 700.00	50.00
Weston	7 000.00	0.00
Marlboro	38 743.30	24.68
Chelsea	124 164.14	682.21
Winchendon	10 001.07	1.33
Haverhill	165 000.00	0.00
Lawrence	14 970.39	599.67
Franklin	17 765.52	......
Cohasset	18 000.00	15.00
Somerville	232 817.00	118.47
Northampton	54 917.55	47.26
Springfield	375 558.61	50.00
North Andover	11 691.60	0.00
Medford	68 588.68	131.83
Bridgewater	16 000.00	0.00
Ware	11 476.73	......
Wakefield	....	2% (I think this is a mistake.)
Holyoke	144 982.00	27.75
Clinton	33 694.71	0.00
Danvers	36 000.00	100.00

	Total Collections.	Amount Uncollectible.
Andover	$22 000.00	......
Brockton	145 889.42	$95.72
Chicopee	76 595.35	75.00
Worcester	448 366.95	239.75
Milton	36 000.00	50.00
Fitchburg	86 656.46	300.00
Lincoln	12 000.00	......
Winthrop	40 006.12	221.97
Boston	2 908 500.00	2 000.00
Milford	57 378.96	18.16
Fall River	240 000.00	......
Watertown	58 032.00	100.00
Newton	14 300.00	500.00
Concord	25 196.49	12.00
Everett	120 000.00	53.75
New Bedford	265 532.77	429.63
Ashland	250 000.00	......
Hartford, Conn.	383 000.00	......
Natick	23 000.00	Very small.
Plymouth	46 362.38	Very small; practically nothing.

EXHIBIT B.

HOUSE......No. 368.

THE COMMONWEALTH OF MASSACHUSETTS.

In the Year One Thousand Nine Hundred and Fourteen.

An Act

To make Unpaid Water Rates Liens on Real Estate.

Be it enacted, etc.

SECTION 1. The owner or owners of real estate shall be liable for the payment of the rate or rates fixed by any city or town for the use of water furnished by such city or town to such real estate or any part thereof; and such rates shall be a lien upon such real estate in like manner as taxes assessed on real estate are liens, and if not paid at the time and as provided by said city or town, shall be collected in like manner to the method of collection of taxes assessed on real estate.

SECTION 2. This act shall take effect upon its passage.

On motion of Mr. George A. Stacy, it was voted that the report be accepted and placed on file.

Mr. William S. Johnson, sanitary and hydraulic engineer, Boston, Mass., then read a paper entitled, "Some Problems Connected with the Design of Small Water-Works Systems." The paper was illustrated by stereopticon views. It was discussed by Mr. Edward V. French, Mr. S. H. McKenzie, Mr. R. D. Chase, Mr. A. R. Hathaway, Mr. Frank L. Fuller, Mr. Henry A. Symonds and Mr. Raymond W. Parlin.

Mr. Joseph N. McKernan, engineer and superintendent, Plainville Water Company, Plainville, Conn., read a paper entitled, "A Study of Rates of the Private Water Companies in Connecticut." The paper was discussed by Mr. S. H. McKenzie and Mr. Raymond W. Parlin.

Adjourned.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee at headquarters, Tremont Temple, at 11 o'clock A.M., Wednesday, January 14, 1914.

Present: President J. Waldo Smith, Frank A. McInnes, James L. Tighe, Richard K. Hale, L. M. Bancroft, and Willard Kent.

The following applications for membership were received and by unanimous vote recommended therefor: Rufus M. Whittet, assistant engineer, Massachusetts State Board of Health, Boston, Mass.; C. C. Covert, district engineer, United States Geological Survey, Albany, N. Y.; Joseph A. Hoy, foreman water-works construction work, Worcester, Mass.; Charles W. Kinney, president Water Board, Northampton, Mass.; Albert H. Tillson, supervisor water works, Northampton, Mass.; Robert R. Livingston, hydro-electric engineer, New York, N. Y.; Daniel J. Higgins, superintendent water works, Waltham, Mass.

Voted, that the Editor be and hereby is authorized to prepare a complete index of the JOURNAL of the Association.

Adjourned.

WILLARD KENT, *Secretary*.

Meeting of the Executive Committee of the New England Water Works Association at Hotel Brunswick, Boston, Mass., January 14, 1914, at 4 o'clock P.M.

Present: President Frank A. McInnes, J. Waldo Smith, Carleton E. Davis, William F. Sullivan, Richard K. Hale, Robert J. Thomas, and Willard Kent.

After discussion it was *voted*, that the next annual convention of the Association be held at Boston, Mass., September 9, 10, and 11, 1914, and that the June outing be held at Worcester, Mass., on the second Wednesday of that month.

Adjourned.

WILLARD KENT, *Secretary*.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Wednesday, February 11, 1914, at 11.30 A.M.

Present: President Frank A. McInnes, William F. Sullivan, James W. Blackmer, Samuel E. Killam, Willard Kent, Richard K. Hale, Lewis M. Bancroft, and George A. King.

Voted, that the President be and hereby is authorized to appoint a committee on papers to be presented to the Association.

Voted, that the President be and hereby is authorized to appoint committees to arrange for the June meeting and the annual convention of the Association.

Application of C. C. Young, director of State Water Survey of Kansas, for membership was received and he was by unanimous vote recommended therefor.

A communication from the National Association of Master Steam and Hot Water Fitters, with reference to a standard schedule for flange fittings, was received and referred to the Committee on Standard Specifications for Cast-Iron Pipe.

Voted, that Editor Richard K. Hale be and hereby is authorized to have prepared a complete index of the JOURNAL of the Association to date.

The Secretary reports the receipt of the renewal certificate of the Treasurer's bond for the ensuing year.

The committee on a certificate of membership presented a design and was by vote authorized and directed to have the design executed and the certificates prepared.

Adjourned.

WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Wednesday, March 11, 1914, at 11.30 A.M.

Present, President Frank A. McInnes, and members William F. Sullivan, Samuel E. Killam, Richard K. Hale, Lewis M. Bancroft, George A. King, and Willard Kent.

Three applications for membership were presented; viz., Almon L. Fales, of firm of Metcalf & Eddy, consulting engi-

neers, Boston, Mass.; Patrick J. Lucey, engineer Holyoke Water Works, Holyoke, Mass.; William H. Butler, superintendent water works, Wakefield, Mass.

One application for reinstatement was received, and it was unanimously voted that the applicant be and hereby is reinstated to membership on his compliance with the requirements of the Constitution.

Voted, That the President be and hereby is authorized to call an extra meeting of the Association in April at his discretion.

Adjourned.

WILLARD KENT, *Secretary.*

Table of Contents.

New England Water Works Association.

ORGANIZED 1882.

Vol. XXVIII. June, 1914. No. 2.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

A STUDY OF CAST-IRON BELL AND SPIGOT PIPE JOINTS BY THE PUBLIC WORKS DEPARTMENT OF THE CITY OF BOSTON.

BY CLARENCE GOLDSMITH.

[*Read April 15, 1914.*]

Cast-iron bell and spigot pipe has been used for the distribution of water in this country since early in the last century. The pipe of that period was cast in 9-ft. lengths without groove in the bell or bead on the spigot, and the joint was made up with lead in much the same way that it is to-day, but in some cases wooden staves were used instead of lead. This pipe was of comparatively small size, and the pressures to which it was subjected were in most cases less than 50 lb. In the course of time larger pipes were required and higher pressures utilized, and about the year 1850 the casting of grooves in the bells and beads on the spigots was begun.

These grooves gave the lead joint greater resistance against blowing out, and the bead facilitated the centering of the pipe, helped to hold the yarn, and contributed something to the holding power of the joint. Joints such as described have been adopted by the New England Water Works and American Water Works associations in their standard specifications, and are now universally used on cast-iron bell and spigot pipe laid for domestic distribution. Where bends, offsets, caps, plugs, blow-off valves, and hydrants are set on the line, it is frequently the practice to

tie them into the line with rods passed either through lugs cast on the pipe, gates and fittings, or through wrought-iron bands bolted around the pipe and fittings, or else to use set screws tapped through bosses cast on the bells and set down on to the spigot end.

In many cases, however, masonry abutments are built up against the line and fittings to resist the thrusts caused by irregularities in alignment and unbalanced pressure on caps and plugs. With the advent of larger sizes of pipe, operated under continually increasing pressures, steel pipe was, in the latter part of the nineteenth century, utilized to a large extent to meet the then more exacting requirements. The life of steel pipe has in many cases been short, due largely to lack of a durable protective coating, and in a measure to electrolytic action. Hence, when the question of a suitable pipe material came up in connection with the design of the earlier high-pressure fire service systems, there was considerable diversity of opinion. In 1897 the city of Buffalo decided to use steel pipe and laid a mile of such pipe with threaded joints, but additions in 1904 and 1906 to this installation were of cast iron. On the other hand, in 1898 the city of Boston used cast-iron pipe with a double groove in the bell for a high-pressure salt-water main of about one mile in length.

The first high-pressure fire service system covering any considerable area was installed in Philadelphia in 1903, and although the original designs contemplated the use of steel pipe, it was finally decided to use cast iron, and a flanged joint was designed for this special service. In 1909 it was decided to largely extend the system, and "Universal" cast-iron pipe was used for this work.

Cast-iron bell and spigot pipe has been used exclusively in the construction of the high-pressure fire service system of New York. The first pipe laid had double semi-circular grooves in the bell and on the spigot, and lugs or rings for wrought-iron bands were cast on all pipes and fittings set where the alignment of the pipe was changed, and on branches and dead-ends, thus providing for the tying of the line together with rods or bolts and nuts. In later installations the dimensions of the grooves were modified, but the practice of tying the lines together is still followed.

The city of San Francisco was the next city to undertake the construction of an extensive high-pressure distribution system. Most careful and complete investigations were made before cast iron was adopted as the material for the pipe lines. Because of the possible trying and exacting conditions which might be imposed upon the distribution system by an earthquake, T. W. Ransom, M. Am. Soc. M. E., and consulting engineer of the Board of Public Works, conducted an extended series of experiments, under the direction of City Engineer Marsden Manson, M. Am. Soc. C. E., on a large number of lead joints of varied design. The results of these experiments led to the development of a joint which was adopted for the work and is producing excellent results. The holding power of this lead joint, however, was not sufficient to permit dispensing with lugs and rods on dead-ends and on fittings out of alignment.

After careful study of the question of material for the pipes of the high-pressure distribution system, the city of Boston has adopted cast iron as unquestionably the best for the purpose. In designing pipe for such service the engineer is largely guided by the results of previous practice, and as the superiority of the joint adopted by the city of San Francisco had been demonstrated, both experimentally and practically, this type of joint was also adopted by the city of Boston. The use of lugs and rods was, however, considered open to criticism and serious objection, it being practically impossible to so adjust the rods in sets of four or six that each would take even an approximate share of its load. The rods, too, are subject to rapid deterioration when buried in earth of the kind found in the greater part of the area in which it is proposed to lay the pipe. The cost of each joint made up with lugs and rods exceeds that of a plain lead joint by approximately \$20 for 20-in. pipe, \$15 for 16-in., \$7 for 12-in., and \$4 for 8-in. These objections suggested the development of a more reliable and permanent method of holding the pipe line in place; but an even more serious objection presented itself to the use of the rod and lug construction in Boston. On account of the great congestion of existing underground structures it is of the utmost importance to economize in space by reducing the clearances to a minimum. The minimum clearances required for pipe with lugs are 35.5

in. for 20-in. pipe, 29.5 in. for 16-in., 24.25 in. for 12-in., and 18.75 in. for 8-in., while without lugs these clearances could be reduced 6, 5, 5, and 4.5 in. respectively. The advantages of the latter construction are, therefore, obvious.

Several methods of overcoming the difficulties which presented themselves were studied. First, the use of set screws in bosses cast on the bells was considered, but their holding power, when of reasonable size, would not be sufficient; and other objections were the difficulty of making them watertight, the expense of drilling and tapping the holes, and the work involved in adjusting the set screws.

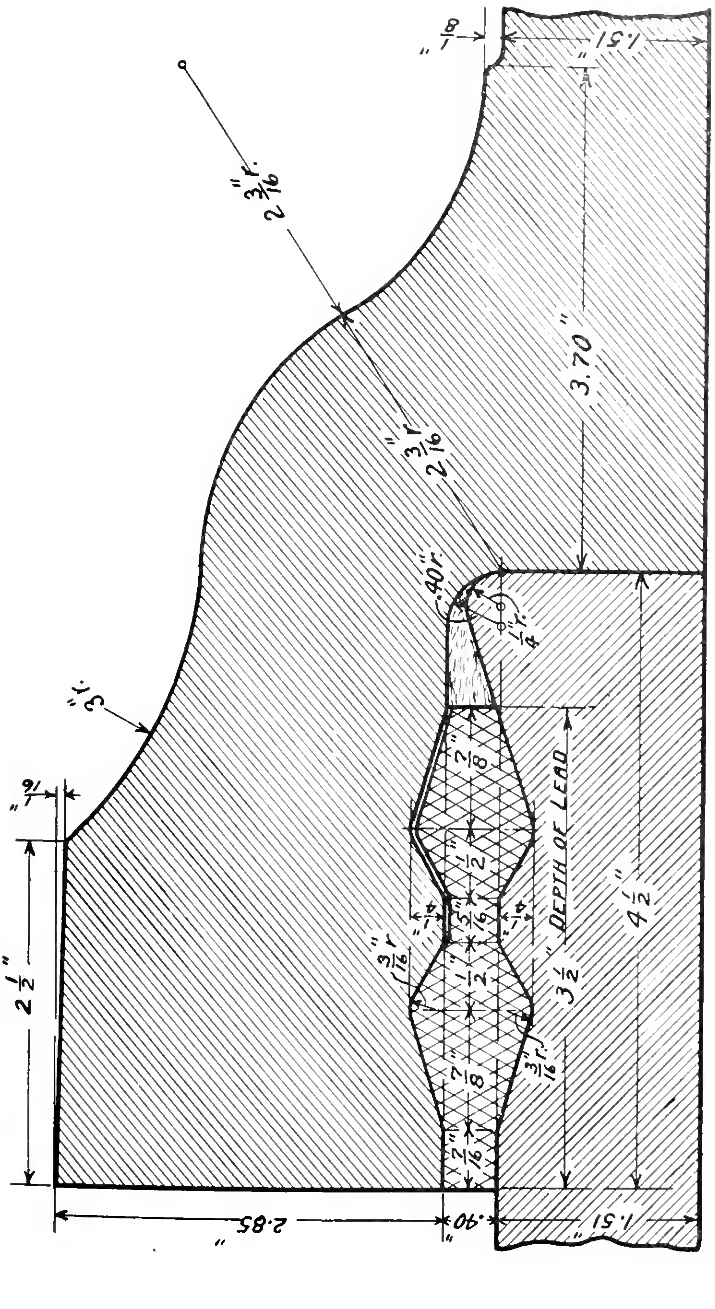
Interlocking wedges cast on the spigot and in the bells were next designed, but were not considered feasible, as the adjustment of the pipe in the ditch would be difficult, and there would be practically no flexibility of the line in case of settlement.

Experiments showed that the failure of double-groove joints of the design adopted was due to the flowing of the joint material rather than to the shearing of this material in the groove of the bell, as in the case of single-groove joints. It was clear, therefore, that the problem would be satisfactorily solved if a material could be found which would offer a much greater resistance to flowing than lead and could be poured and driven with moderate facility, and yet would not be so rigid as to prevent a sufficient movement in the joint to allow for settlement of the pipe line.

The materials available for an alloy of the character required are:

	Melting Point. Degrees Fahr.	Tensile Strength. Pounds.
Lead	600	1 600 to 2 400
Tin	450	3 500
Bismuth	500	6 400
Zinc	780	5 000 to 6 000
Antimony	1 150	13 000

To make the various joints for testing, 20-in. caps and plugs with double grooves of the design adopted cast in the bell and turned on the spigot were used. The depth of the bell in all cases was 4.5 in., and the joints were made up by centering the plug in the cap and yarning the joint until the face of the yarn, which was driven home with a hammer, was 3.5 in. from the face of the



SECTION OF 20-INCH BELL & SPIGOT

FIG. 1. TYPICAL LEAD JOINT FOR HIGH-PRESSURE PIPE.

bell. The plug was then tipped at an angle of about 45 degrees, a jointer adjusted, and the joint material poured. A round jointer provides for a sufficient lip of lead on the outside to permit of the joint's being flush when driven. If a flat jointer is used, its inner side next the joint should be beveled at 45 degrees for a distance away from the pipe equal to the thickness of the joint in order to provide sufficient lip. The thickness of the joints tested varied from 0.35 to 0.75 in. The caps were tapped with two 0.25-in. holes, one to receive the connection from a small pump capable of raising the pressure to 3 000 lb., the other to provide a vent for air.

In the first twelve tests, observations to determine the movement of the joint were made with a rule, and readings were taken to one sixteenth of an inch at two points on the plug. The pressure was raised in increments of 100 lb., and maintained constant for intervals of, generally, five minutes. In this series of tests two joints were made up with Omaha lead, four with 96 per cent. lead and 4 per cent. tin, one with 94 per cent. lead and 6 per cent. tin, two with 97 per cent. lead and 3 per cent. tin, two with 98 per cent. lead and 2 per cent. tin, and one with lead wool hand driven. The data obtained showed that an alloy of lead and tin made a joint which offered a greater resistance to the unbalanced pressure between the cap and plug than Omaha lead; that as the proportion of tin in the alloy is increased, the resistance of the joint is increased; that lead wool offers a greater resistance than Omaha lead, but not so great as any of the alloys used; that the joint did not reach its maximum power of resistance until the plug had moved some little distance out of the cap; that the alloy could be poured with about the same facility as lead, but that the driving of the joint required more time as the quantity of tin was increased; also that the joints when driven are watertight, but when a joint moved, a slight leakage was observed, which, however, disappeared before the joint had moved out far enough to develop its maximum strength. The method of making the observations, however, was not sufficiently refined to determine exactly when the joint attained its greatest strength, and the intervals during which pressures were maintained were not long enough to assure equilibrium of the joint.

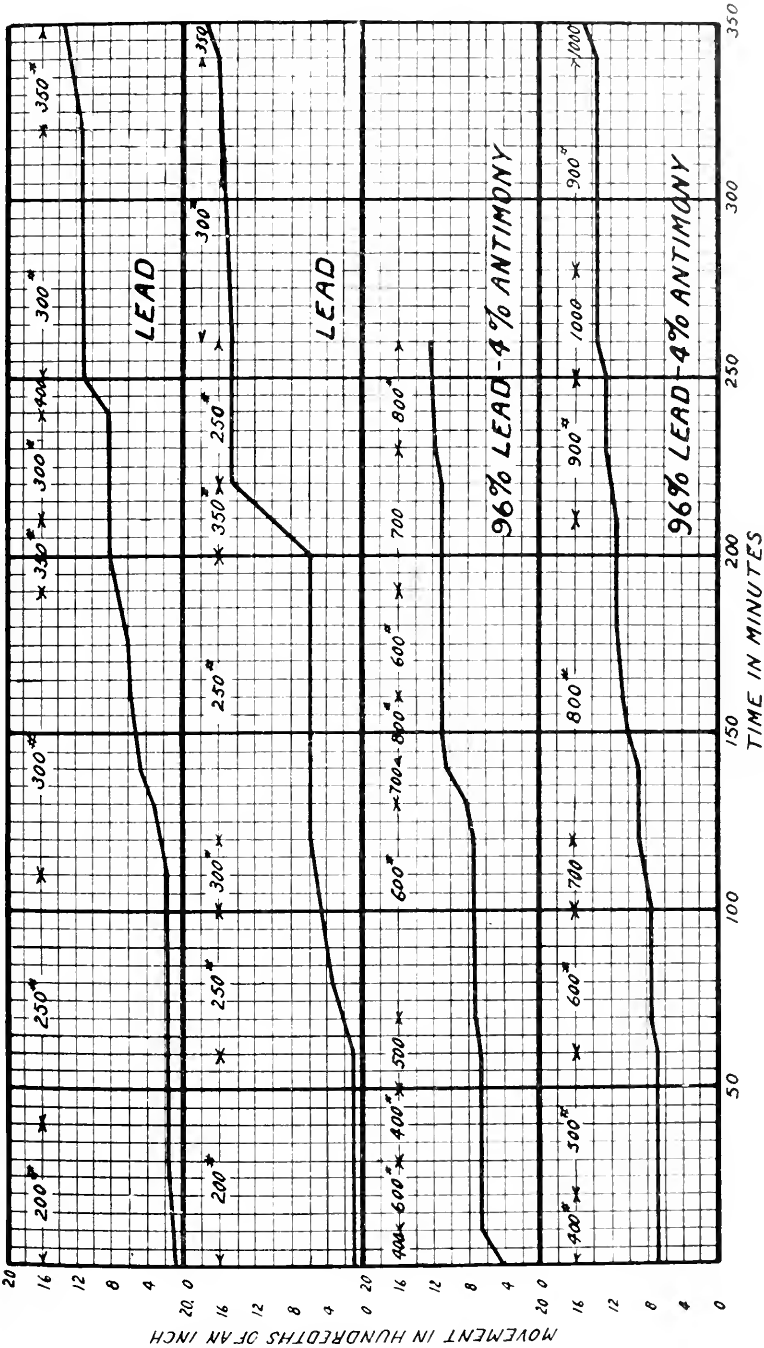


FIG. 2. · JOINT MOVEMENT.

A series of three tests (Nos. 14 to 16) was run in which measurements to 0.01 in. were taken by dividers at four points at the ends of diameters at right angles to each other, and the time interval increased — in the last test to fifty-five minutes. In two of these tests an attempt was made to reproduce the condition which exists when the alignment of the pipe is changed in the trench, that is, in which one side is home and the other side is in one case 0.5 in. and in the other 1 in. from being home, corresponding to throws of 3 in. and 6 in., respectively, in the trench for a full length of the size of pipe being tested. This condition did not appear to affect the resistive power of the joint.

These preliminary tests having proved that it was possible to make a joint strong enough to permit tie rods to be dispensed with, a series of thirteen tests was next run under more reliable and accurate methods of measuring the joint movement, and with pressures maintained for a time sufficient to assure that the joint was in equilibrium. Three of these tests were made with Omaha lead, one with lead wool, three with an alloy of lead and tin, three with lead and antimony, and three with lead, tin, and antimony.

Although the results obtained with a 4 per cent. tin alloy were fairly satisfactory, the ultimate resistance of the joint was only about 500 lb., and the cost of tin is about 50 cents a pound, while antimony costs but 10 cents a pound and reduces much more than does tin the tendency of the lead to flow. In melting the lead and antimony to form the alloy, it was found desirable to melt the antimony in a separate pot and add it to the molten lead, for if they were melted in the same pot, the high temperature required to melt the antimony would cause a burning of the lead. The temperature required to melt the metals after they are synthetized is 900 fahr., or approximately halfway between the temperatures required to melt them separately, and when heated to a proper temperature for pouring, the oxidation of the alloy appears to be less than that of lead.

In the tests of joints made up with 96 per cent. lead and 4 per cent. antimony a number of small leaks developed between the pipe and the joint material, even when the joint was carefully driven, showing that the ring of alloy does not contract sufficiently around the pipe to make a watertight joint, whereas lead or a

lead-tin alloy assures watertightness. For this reason it was not practical to adopt this lead-antimony alloy, although its holding power was satisfactory.

The three tests made on the alloy composed of 96 per cent. lead, 2 per cent. antimony, and 2 per cent. tin showed that the alloy can be easily melted and poured, requires only about one third more time to drive than lead, and meets the requirements in other respects. This alloy was, therefore, adopted as the best material for the joint, and the joints thus made were found capable of resisting the unbalanced force developed by a pressure of 700

Nominal Diameter of Pipe. Inches.	Number of Rods.	Diameter of Rods. Inches.	Strength of Set of Rods in Pounds.	Resistance of Plain Lead Joint in Pounds.	Combined Strength of Lead Joint and Rods in Pounds.	Resistance of Lead-Antimony-Tin Joint in Pounds.	Maximum Allowable Pressure for Lead Joints in Pounds.	Maximum Allowable Pressure for Lead-Antimony-Tin Joint in Pounds.
8	4	1	52 800	47 400	100 200	133 100	540	1 550
12	4	$1\frac{1}{4}$	85 700	68 700	154 400	192 900	390	1 100
16	6	$1\frac{1}{4}$	128 600	89 800	218 400	252 300	320	900
20	6	$1\frac{1}{2}$	186 500	111 200	297 700	312 000	250	700
24	6	$1\frac{3}{4}$	251 400	133 300	384 700	374 200	200	600

lb. per sq. in. on the 20-in. plug, amounting to 312 000 lb., which, since the circumference of the joint is 73.6 in., is equivalent to a resistance of 4 240 lb. per linear inch. The pressures which can be carried on plugs of other sizes may be readily calculated, and are shown in the preceding table, together with the calculated ultimate holding power of lead joints tied together with rods.

It will be seen from the foregoing table that the strength of the alloy joint is fully as great as the combined strength of the lead joint and rod for sizes of pipe up to and including 20 in. Although 20-in. pipe is to be the largest in the proposed system, 24 in. has been included in the table because pipe of this size has been used in some installations. A study of the plots of the various tests shows that the joint does not attain its maximum resistance to the internal pressure until the plug has moved out about 0.15 in. This is due to the fact that the alloy contracts in cooling, and as the

calking does not affect the material in the inner groove, this part of the joint does not offer its resistance until it is brought into bearing by the outward movement of the spigot end. During the progress of the several tests no leakage was observed until a pressure of 500 lb. per sq. in. was reached, and the leakage at this pressure, which was small, ceased before the joints had attained their ultimate strength.

In order to make a more complete and practical test of this joint material, a 20-in. line, consisting of a length of pipe, four $\frac{1}{16}$ bends, and a second length of pipe, was set up on blocking, and the ends were closed with a cap and plug. The joints were made up with yarn and an alloy composed of 96 per cent. lead, 2 per cent. antimony, and 2 per cent. tin, except that joint No. 6 was poured with a lead-tin alloy. All joints were driven with dog tools and finished with hand tools. The movement of the line while under pressure was recorded in the following manner:

A $\frac{1}{4}$-in. hole about one inch deep was drilled in the top of each of the seven bells, and a wooden pin, into which a sewing needle, pointing up, was inserted, was set in the hole. A stake was driven on either side of the pipe opposite each joint, so that a crosspiece extended over the pipe would be at right angles to the axis of the pipe. A small board upon which cross-section paper was mounted

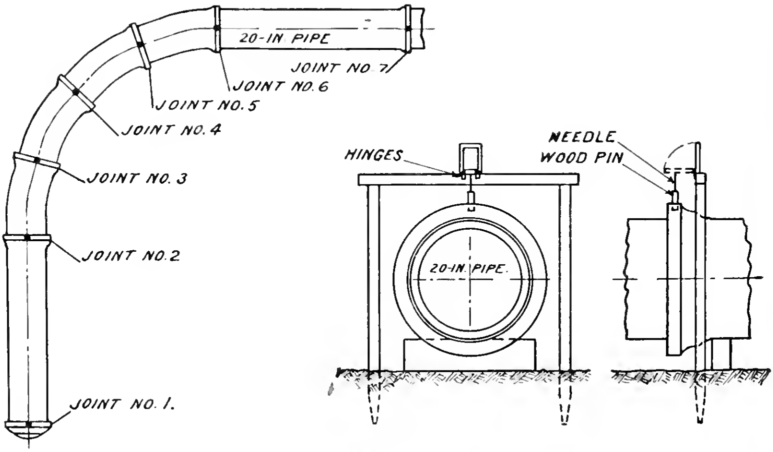
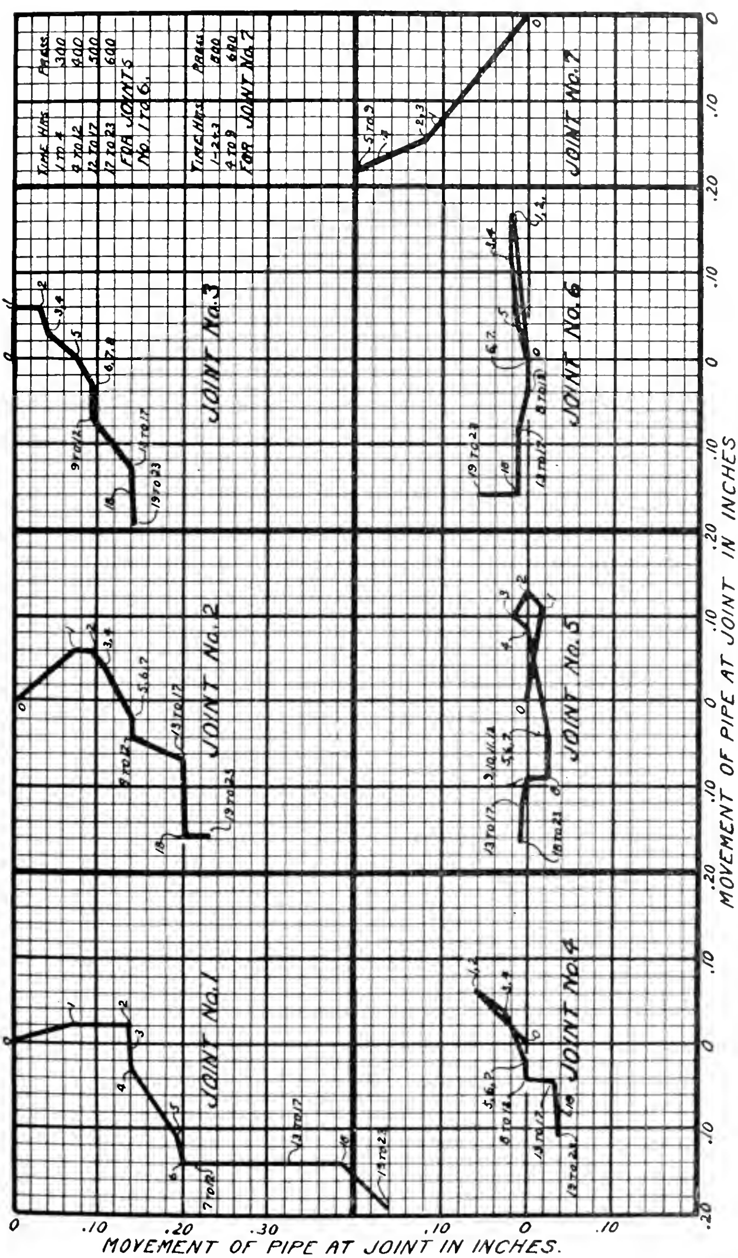


FIG. 3. EXPERIMENTAL 20-INCH LINE.



MOVEMENT OF JOINTS IN 20 INCH PIPE LINE

Fig. 4.

was so hinged to each crosspiece that the needle in the wooden pin beneath it would just pierce the paper when the board was in its horizontal position. Holes were so drilled and tapped in the line that it could be filled and emptied, and provision was made to vent the line of air and to attach a pressure pump. After the line was filled with water a record was taken of the position of each bell by swinging down the boards on which the cross-section paper was mounted until a hole was pricked by the needle point. The pump was then attached and the pressure was raised to 300 lb. per sq. in. and maintained for four hours. During the last two hours of this period the line was in equilibrium and no leakage developed. The pressure was next raised to 400 lb. per sq. in. and maintained for eight hours, and during the last four hours the entire line was in equilibrium, and no leakage was apparent. The pressure was then raised to 500 lb. per sq. in., and joint No. 6, which had been made up with an alloy of lead and tin, did not come into equilibrium, but continued to draw out of the bell, and when it had drawn out 1.9 in. the test was discontinued. This joint was melted out and a new joint of lead-antimony-tin alloy was made, and the test continued. The pressure was again raised to 500 lb per sq. in. and maintained for three hours, then raised to 600 lb. per sq. in. and maintained for six hours. During the last five hours the pipe line was in equilibrium, but several of the joints sweated during the entire time. The leakage on joint No. 1 was the greatest, and equaled six fluid ounces per hour, which is equivalent to a leakage of one fourth of a gallon per linear foot of joint for twenty-four hours. An attempt was now made to raise the pressure to 700 lb. per sq. in., but the capacity of the pump, which had a displacement of only one seventh of a fluid ounce per stroke, was not sufficient. A second pump of larger capacity was secured, and with the two pumps in service a pressure of 700 lb. per sq. in. was maintained for fifteen minutes, when one of the bends burst. During this period the leakage increased but slightly, and no observations were taken.

The results obtained from the foregoing experiments showed that the lead-tin-antimony alloy would amply fulfill the requirements for making joints in cast-iron bell and spigot pipes with grooves of the design adopted. Inasmuch as it has frequently

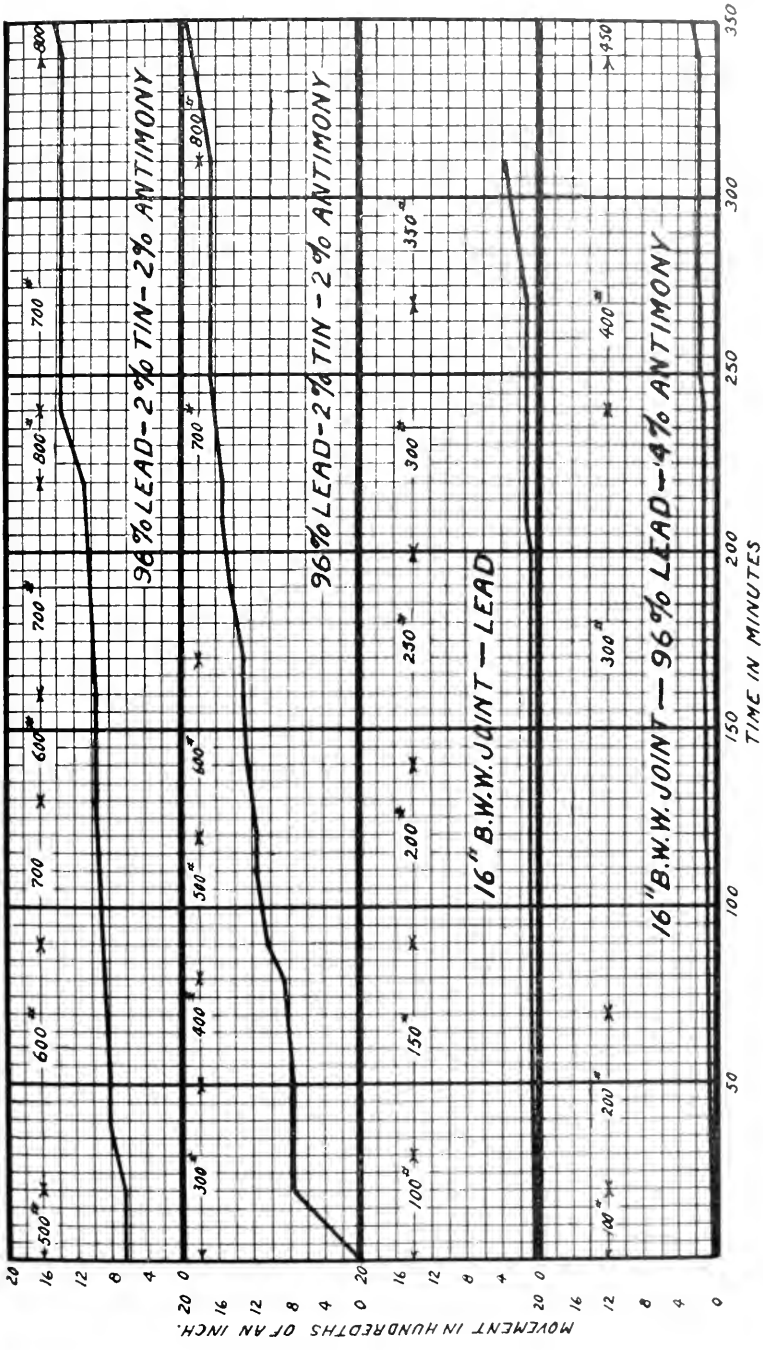


FIG. 5. JOINT MOVEMENT.

been necessary in the construction of ordinary low-pressure pipe lines for the distribution of domestic supply to tie the various fittings into the line with rods or set screws, or sometimes to build up abutments to secure them, it is most desirable to ascertain the effect of an alloy in the making up of joints in ordinary cast-iron pipe. Two 16-in. joints of Boston Water Works design were, therefore, made up, one with lead and one with an alloy of 96 per cent. lead and 4 per cent. antimony. The lead joint withstood a pressure of 300 lb. per sq. in., while the lead-antimony joint withstood a pressure of 400 lb. per sq. in., showing an increase of one third over and above the holding power of the lead joint.

MORTALITY RATES OF PHILADELPHIA IN RELATION TO THE WATER SUPPLY.

BY J. A. VOGLESON, CHIEF BUREAU HEALTH.

When any important sanitary measure is accomplished, we look to the mortality rates of the people affected, for the final value of the improvements. The filtration of the city water supply of Philadelphia was such a measure, and while the time which has elapsed since the last of the five filtration plants was put into service, in the latter part of 1911, is too short to permit complete analysis of the results from filtration, yet the marked changes which appeared in the typhoid rate, as district after district was added to the filtered water area, afford interesting data for examination.

Philadelphia was long scourged with typhoid fever, and the principal cause was finally attributed to the polluted rivers from which the city water supply is obtained. Thus, after many investigations, looking toward improving the water supply, the city began in 1900 active construction of the filtration works. Other sanitary measures to protect the water supply had been adopted in preceding years, — notably the acquisition of land now embraced in Fairmount Park, which was purchased from time to time for sites for pumping stations, reservoirs, and for protective purposes; the construction of the Schuylkill intercepting sewer, built to prevent city sewage from reaching the intakes of pumping stations on that river; and also the work of the State Health Department, which is progressing with increasing results toward sewage treatment for towns in the populous Schuylkill Valley.

Analysis of the mortality rates from 1862, which was the first year of complete record after the Registration Act of 1860, shows by decennial averages that the typhoid fever rate alternately fell and rose but did not again reach the high average of 79.9 per 100 000 which prevailed for the period 1862–70. It was not until

in 1909, when the city received 80 per cent. filtered water plus 14 per cent. sterilized raw water, that a decided break was made in the typhoid rate, although a reduction from the high rate of 72.4 for 1906 had been made in 1908, when the rate had dropped to 34.8, and the influence of the local reduction in districts receiving filtered water was reflected in the city rate. From that year the decline has been consistent to the 12.5 rate of 1912, and we may safely conclude that a large percentage of the cases of typhoid fever in Philadelphia was from water infection, and the reports of sanitarians which preceded the work of filtration have been amply verified.

On Fig 1, the total mortality and typhoid rates, the ratio of typhoid to total mortality, the percentage of filtered water in the city supply, and other data have been plotted to show their relations.

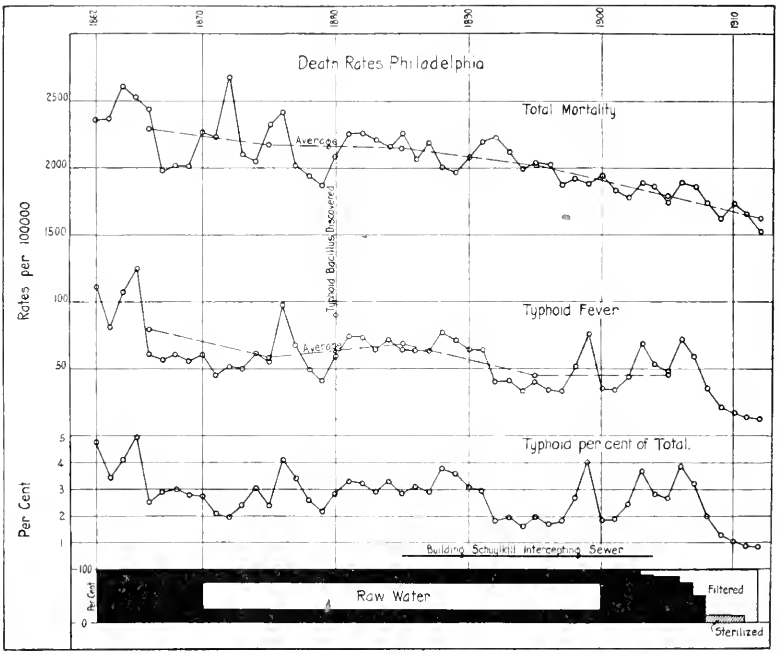


Fig. 1. Death-Rates in Philadelphia, 1862–1912.

The general downward trend of the total mortality rate since 1862 is shown on Fig. 1. The yearly fluctuations and the tendency to group in high and low levels are also shown. In all probability we may expect these fluctuations to continue in the future, yet we trust they will be in more modified form than in the past. In fact, the record for eight months of 1913 indicates that the mortality for this year will be higher than for 1912, which is the lowest year to this date.

TABLE NO. 1.

TOTAL DEATH-RATE AND TYPHOID DEATH-RATE BY DECADES, PHILADELPHIA

Period.	Mortality per 100 000. Total.	Typhoid.	Per Cent. Typhoid of Total.
*1862–70	2 291.2	79.9	3.49
1871–80	2 170.2	58.1	2.69
1881–90	2 142.9	68.5	3.19
1891–1900	2 018.7	44.6	2.17
1901–1910	1 792.2	45.2	2.57
1911	1 650	14.1	.85
1912	1 522	12.5	.82

* Nine years.

TABLE NO. 2.

CHANGE IN TOTAL AND TYPHOID MORTALITY RATES PER 100 000.

Period.	Total.	Per Cent. of Average. Previous Period.	Typhoid.	Per Cent. of Average. Previous Period.
1861–1871 1870–1880	121.0 (dec.)	5.28	21.8 (dec.)	27.31
1871–1881 1880–1890	27.3 (dec.)	1.26	10.4 (inc.)	17.91
1881–1891 1890–1900	124.2 (dec.)	5.79	23.9 (dec.)	34.92
1891–1901 1900–1910	226.5 (dec.)	11.24	0.6 (inc.)	1.35
1891 1900–1911	368.7 (dec.)	18.29	30.5 (dec.)	68.41
1891 1900–1912	496.7 (dec.)	24.58	32.1 (dec.)	72.00

The curve for typhoid fever consistently slopes downward with increased percentage of filtered water, and the effect of sterilized raw water is also clearly reflected. We can confidently predict that the low city rate of 12.5 per 100 000 will ultimately go still lower when all of the causes of typhoid fever have been brought under control, for we already have a large isolated section of the city which has a typhoid rate under 6 per 100 000.

TABLE NO. 3.

Total Mortality and Typhoid Rates and Per Cent. of Typhoid Mortality, Philadelphia.

Year.	Rates per 100 000. Total Mortality.	Typhoid.	Per Cent. of Total.
1862	2 360	111.4	4.73
1863	2 373	81.2	3.42
1864	2 610	106.6	4.09
1865	2 525	124.9	4.95
1866	2 439	60.6	2.49
1867	1 976	57.2	2.89
1868	2 039	60.4	2.96
1869	2 027	56.4	2.78
1870	2 272	60.7	2.67
1871	2 231	45.3	2.05
1872	2 679	52.1	1.95
1873	2 097	50.1	2.39
1874	2 049	62.1	3.03
1875	2 323	55.2	2.37
1876	2 417	97.7	4.04
1877	2 013	68.2	3.38
1878	1 937	49.7	2.56
1879	1 865	41.4	2.22
1880	2 091	58.9	2.81
1881	2 248	74.3	3.31
1882	2 262	73.3	3.23
1883	2 213	63.8	2.88
1884	2 155	71.3	3.31
1885	2 253	64.2	2.85
1886	2 059	63.6	3.09
1887	2 185	62.5	2.86
1888	2 004	77.2	3.82
1889	1 974	70.7	3.58

TABLE NO. 3. — *Continued.*

Year.	Rates per 100 000 Total Mortality.	Typhoid.	Per Cent. of Total.
1890	2 076	63.6	3.06
1891	2 185	63.9	2.93
1892	2 225	40.3	1.81
1893	2 120	40.9	1.93
1894	1 990	32.5	1.63
1895	2 044	40.3	1.97
1896	2 017	33.8	1.68
1897	1 872	33.2	1.76
1898	1 918	51.5	2.69
1899	1 878	74.9	3.99
1900	1 938	34.7	1.79
1901	1 826	33.6	1.84
1902	1 770	43.6	2.46
1903	1 889	69.4	3.68
1904	1 856	52.8	2.85
1905	1 740	47.6	2.74
1906	1 886	72.4	3.87
1907	1 859	59.3	3.19
1908	1 744	34.8	1.99
1909	1 623	21.1	1.30
1910	1 729	17.4	1.05
1911	1 650	14.1	.85
1912	1 522	12.5	.82

TABLE NO. 4.

PER CENT. OF FILTERED WATER IN CITY SUPPLY, PHILADELPHIA.

Year.	Per Cent. Filtered.	Year.	Per Cent. Filtered.	Per Cent. Raw Water Sterilized.
1902	0	1907	25	...
1903	2.5	1908	48	...
1904	10.0	1909	86	14
1905	14.0	1910	86	14
1906	14.0	1911	87	13
1907	25.0	1912	100	...

The general mortality rate of Philadelphia has declined since the period 1862–70, and the first marked reduction occurs in the decade 1901–10, during which period the city was generally in-

creasing its filtered water districts. How much of this reduction is due to improved water supply and how much to other agencies for improving the public health is most difficult to answer. The general hygienic advance of the past fifteen years, and the increased activities in specially directed lines of health work, which will be referred to later, must not be lost sight of in reaching conclusions, especially as it is found that a large per cent. of the reducduction in the total death-rate is due to the saving of lives of children under one year of age.

TABLE NO. 5.

PERCENTAGE OF TOTAL DEATHS OCCURRING BY AGE PERIOD, AND OF PERSONS LIVING IN THOSE PERIODS, PHILADELPHIA.

	Percentage of Total Deaths.			Percentage of Total Living.		
Age Period.	In 1892.	In 1902.	In 1912.	In 1890.	In 1900.	In 1910.
Under 2........	30.0	25.6	20.3	3.49	4.06	4.00
2–10........	12.7	5.9	5.5	15.57	15.75	14.58
10–20........	3.8	4.5	3.4	18.37	16.99	17.58
20–30........	8.4	8.5	7.3	21.59	20.52	19.91
30–40........	9.0	10.7	9.3	16.20	17.16	16.80
40–50........	7.6	9.7	11.1	10.98	11.64	12.55
50–60........	8.1	9.9	12.6	7.14	7.26	7.86
60–70........	8.5	10.9	13.2	4.22	4.14	4.26
70–80........	7.4	9.2	11.4	1.77	1.77	1.84
Over 80........	4.5	5.1	5.9	.47	.43	.46
Unknown.......	...	...	...	.20	.28	.16

To show the trend of span of life in Philadelphia, Table No. 5 has been prepared, and in so far as these data show, the changes in distribution of deaths by age periods had their inception before the city had filtered water.

Thus, respectively in 1892, 1902, and 1912, 30.0, 25.6, and 20.3 per cent. of the deaths occurred in the age period under two years, with differences of 4.4 per cent. and 5.3 per cent. between years having raw water only and a year having raw water and one having filtered water respectively at ten-year intervals.

Mortality in Philadelphia was not registered under the International Classification of the Causes of Death until 1904, thus giving too brief an interval for a complete balancing of the changes in the total death-rate by disease groups. However, certain dis-

eases and the age-period under one year have been selected for examination as to the trend of their rates from 1890–1912, and are set forth in Table No. 6.

TABLE NO. 6.

TOTAL DEATH-RATE, DEATH-RATES FROM CERTAIN DISEASES, AND DEATH-RATES UNDER ONE YEAR OF AGE, PER 100 000 POPULATION, 1890–1912 INCLUSIVE, PHILADELPHIA.

Year.	Total Death-Rate.	Typhoid Fever.	Tuberculosis of Lungs.	Pneumonia.	Bronchitis.	Diarrhea and Enteritis.	Diphtheria and Croup.	Heart Disease.	Kidney Diseases.	Cancer.	Early Infancy.	Children under One Year of Age.
1890	2 076	63.6	264.5	192.5	50.0	160.6	90.0	133.4	70.6	51.3	223.8	50.5
1891	2 185	63.9	246.5	197.4	50.4	180.4	127.4	138.8	81.0	53.5	224.0	51.3
1892	2 225	40.3	247.8	202.3	56.6	187.8	156.3	145.0	79.9	52.1	226.4	52.1
1893	2 120	40.9	239.4	202.1	50.7	184.6	103.9	151.5	84.8	55.0	225.7	51.2
1894	1 990	32.5	221.5	188.0	42.2	171.3	122.5	133.0	83.2	51.7	212.9	48.0
1895	2 044	40.3	210.4	220.9	48.0	168.1	115.9	144.6	84.2	58.6	212.3	47.1
1896	2 017	33.8	211.5	227.5	44.4	169.0	97.2	145.1	87.2	56.9	198.3	43.3
1897	1 872	33.2	196.7	224.3	38.9	126.3	121.4	133.9	89.1	56.6	161.9	38.0
1898	1 918	51.5	208.8	200.0	35.1	158.0	93.0	145.3	90.9	54.0	168.2	40.6
1899	1 878	74.9	221.7	191.4	30.7	123.2	76.8	143.8	96.4	61.3	159.1	36.0
1900	1 938	34.7	210.0	228.7	34.2	134.1	79.3	145.4	89.3	62.6	175.4	39.0
1901	1 826	33.6	222.9	195.0	28.7	124.0	47.6	140.9	109.0	58.6	164.8	35.1
1902	1 770	43.6	211.0	220.5	28.3	114.1	37.4	147.0	103.6	63.7	155.7	34.3
1903	1 889	69.4	221.0	231.5	32.3	120.4	44.1	177.7	103.9	62.7	139.5	33.5
1904	1 856	52.8	221.0	210.9	34.7	128.2	38.4	172.0	144.2	73.6	100.4	35.9
1905	1 740	47.6	197.0	159.7	35.2	141.5	31.4	158.0	151.4	72.1	91.5	35.5
1906	1 886	72.4	215.0	183.7	44.0	165.3	37.1	162.0	156.7	76.7	87.0	39.9
1907	1 859	59.3	209.7	182.6	36.2	135.5	33.9	178.1	166.5	77.6	93.2	36.9
1908	1 744	34.8	200.2	173.0	34.8	130.4	32.5	165.9	154.9	80.6	84.2	35.2
1909	1 623	21.1	187.3	145.2	35.4	123.3	32.7	158.8	153.0	83.4	79.9	31.9
1910	1 729	17.4	184.8	182.7	34.4	163.6	31.7	177.2	150.2	83.0	71.8	33.7
1911	1 650	14.1	187.3	165.3	28.9	126.5	31.5	181.5	149.5	85.7	72.7	29.9
1912	1 522	12.5	165.2	136.5	26.3	101.6	24.2	198.1	149.4	87.8	87.9	25.9

Diarrhea and enteritis will be noted as having a downward trend from a high rate of 187.8 per 100 000 in 1892 to a lower rate of 114.1 in 1902, too early to be influenced by the improved water supply, and then followed by succeeding changes of rise and fall to take its last downward trend in 1910 to its lowest rate of 101.6

per 100 000 in 1912. It should be here noted that by far the largest percentage of deaths from these causes occur among infants, and that the peaks of this curve do not coincide with those of the curve of typhoid fever, with the exception of 1906.

In the Health Department we are inclined to consider that the changes in the rate have been influenced largely by work for improved milk supply and the campaign for the reduction of infant mortality, which has been carried on for some years, but with increased activity since 1906.

If the improved water supply caused the decrease in death-rate of children under one year of age from 1906 to 1912, what was responsible for the sharp decline from 1892 to 1897? Possibly children do not have the same diseases now that they did in the earlier period, and there may be a new series of illness now being overcome. We are, however, informed by physicians that babies are still subject to and have the same ailments, but that they are being better cared for. This decrease is in all probability largely due to improved milk supplies and to education in the care of infants.

The Health Department of Philadelphia has with a small corps of nurses, working in the congested districts, consistently reduced not only the death-rate among infants, but also there has followed a decrease in the death-rates from communicable diseases which was not shared in by wards adjacent to the ones in which this work was done. This happened not only in one year, but consistently followed in all the wards to which these nurses were transferred from year to year. Due credit for reduction of infant mortality must also be given to social and charitable organizations, working under private auspices, in ascribing the causes for the city reduction in infant mortality. Undoubtedly wholesome water is a factor, but proper food and housing and a host of other factors must not be overlooked.

Certain sections of the city have received a filtered water supply for longer periods than others, and in so far as the data will permit, examination will be made for results in those sections. It has previously been stated that a large percentage of the typhoid in Philadelphia was from water infection. This was first demonstrated when the Roxborough Filter Stations were put into service,

furnishing water to the twenty-first and twenty-second wards from 1903, and from these wards we have data for the longest period of comparison of raw and filtered water. This is a unit which changed in population from 72 229 in 1890 to 110 605 in 1912, in the meantime having one of these wards reduced in area. They occupy, in the main, high lying ground in the northwest part of the city and are principally residential wards, although they have also a mill district along the Schuylkill River. The variations in rates for these wards parallel quite strikingly the variations of the entire city.

TABLE NO. 7.

Total Death-Rate and Death-Rates from Certain Diseases per 100 000 Population, 1890–1912 Inclusive, Twenty-First and Twenty-Second Wards.

Year.	Total Death-Rate.	Typhoid Fever.	Tuberculosis of Lungs.	Pneumonia.	Bronchitis.	Diarrhea and Enteritis.	Diphtheria and Croup.	Heart Disease.	Kidney Diseases.	Cancer.
1890	1 626	69.4	227.8	148.6	34.7	155.5	33.3	116.7	58.3	61.1
1891	1 802	85.5	182.7	149.3	53.3	133.3	103.0	116.0	77.3	46.7
1892	1 730	48.0	210.4	137.7	37.7	139.0	90.9	110.4	72.7	49.3
1893	1 751	55.0	178.7	175.0	42.5	155.0	68.7	120.0	81.2	72.5
1894	1 464	19.5	165.8	96.3	24.4	132.9	98.8	91.5	70.7	51.2
1895	1 651	34.1	178.8	158.8	36.5	142.4	80.0	133.9	81.2	58.8
1896	1 653	33.3	158.3	173.6	34.5	116.1	42.5	156.3	107.9	55.2
1897	1 564	45.6	195.3	150.0	28.9	116.7	88.9	120.0	73.3	55.6
1898	1 599	31.5	165.2	122.8	18.5	116.3	80.4	151.1	94.6	57.6
1899	1 521	73.0	184.2	142.1	23.2	101.1	40.0	138.0	89.5	60.0
1900	1 573	35.1	162.2	196.9	30.9	105.0	34.0	108.2	115.6	60.8
1901	1 477	22.9	146.0	160.0	28.0	90.0	54.0	130.0	99.0	71.0
1902	1 530	22.1	159.3	190.7	38.4	107.0	52.3	147.7	95.3	61.6
1903	1 630	62.5	164.8	156.8	37.5	96.6	22.7	189.8	105.7	72.7
1904	1 645	29.7	170.0	194.6	30.8	96.7	24.2	180.2	116.5	82.4
1905	1 478	20.4	137.6	155.9	21.5	103.2	19.4	148.4	131.2	73.1
1906	1 471	25.1	170.8	130.2	38.5	115.7	19.8	150.0	116.7	72.9
1907	1 552	27.6	151.0	138.8	19.4	109.2	14.3	189.8	117.3	81.6
1908	1 559	30.7	159.4	124.7	26.7	103.0	10.9	181.2	134.7	86.1
1909	1 408	9.7	122.3	110.7	36.9	91.3	11.6	170.9	134.0	86.4
1910	1 303	15.1	113.2	132.1	28.3	112.3	21.7	180.2	126.4	111.3
1911	1 471	19.4	133.3	129.6	21.3	99.7	28.7	200.0	124.1	94.4
1912	1 323	35.1	103.0	103.0	27.9	85.6	18.2	196.4	103.6	79.3

The typhoid shows marked fluctuations, and while the reduction to 20.4 per 100 000 for 1905 was marked, yet in the year 1894 these wards had a rate of 19.5 per 100 000. This, we believe, is accounted for by reason of the large subsiding basins at the Roxborough Station having afforded a certain amount of protection in previous years. These wards have suffered from local milk epidemics and from broken mains, causing interruption in the service. Had it not been for such causes in 1910–11–12, we believe the low typhoid rate of 9.7 per 100 000 attained in 1909 would have been lowered in the subsequent years.

TABLE NO. 8.

TOTAL DEATH-RATE AND DEATH-RATES FROM CERTAIN DISEASES PER 100 000 POPULATION, 1890–1912 INCLUSIVE, WEST PHILADELPHIA.

Year.	Total Death-Rate.	Typhoid Fever.	Tuberculosis of Lungs.	Pneumonia.	Bronchitis.	Diarrhea and Enteritis.	Diphtheria and Croup.	Heart Disease.	Kidney Diseases.	Cancer.
1890	2 633	70.6	367.5	191.9	37.4	171.7	104.0	175.8	116.2	72.7
1891	2 612	53.8	339.4	220.0	33.6	153.8	82.7	160.6	169.2	73.1
1892	2 818	44.0	324.8	236.7	56.0	185.3	111.9	211.9	171.6	59.6
1893	2 544	33.4	313.1	226.3	35.1	176.3	88.6	175.4	157.9	62.3
1894	2 587	22.7	296.6	217.6	33.6	166.4	75.6	153.8	142.0	58.0
1895	2 435	35.5	297.7	174.2	35.5	151.6	73.4	168.5	150.8	60.5
1896	2 208	25.6	278.3	220.1	24.8	125.6	69.8	165.1	169.0	58.9
1897	2 029	40.4	262.7	227.6	32.8	117.2	59.0	162.7	191.0	65.7
1898	2 104	49.1	291.4	174.8	36.7	161.9	74.8	164.0	172.7	71.9
1899	2 205	78.8	340.4	179.0	28.0	107.0	88.2	194.4	193.7	76.2
1900	2 670	39.9	405.4	241.2	28.4	137.2	68.2	240.5	229.7	99.8
1901	2 718	53.1	430.4	245.6	29.7	131.0	53.2	195.6	367.7	99.4
1902	2 480	79.6	390.5	242.3	25.0	108.3	20.8	193.4	316.7	108.3
1903	2 509	88.1	379.2	263.5	25.3	101.7	37.1	262.9	256.7	94.9
1904	2 441	78.6	412.7	231.4	26.6	126.1	26.6	231.4	243.6	102.0
1905	2 263	33.8	348.5	167.2	27.3	145.8	21.7	135.9	247.5	101.0
1906	2 090	45.2	300.0	193.7	36.5	158.7	33.7	173.6	182.1	98.1
1907	1 801	28.9	172.5	169.3	30.7	130.7	36.7	169.7	164.2	98.2
1908	1 695	25.4	194.3	143.0	22.4	131.6	32.5	173.2	150.0	95.6
1909	1 510	14.7	190.8	127.7	29.4	104.2	25.2	162.2	148.3	100.0
1910	1 822	11.7	190.3	186.7	26.6	177.0	24.2	187.9	166.5	96.0
1911	1 678	9.3	179.5	164.7	22.1	127.1	24.0	189.9	158.1	105.8
1912	1 561	5.9	165.7	142.2	20.9	130.6	19.8	207.8	147.4	89.9

The figures for the other diseases show the general characteristics previously explained in detail for the city as a whole.

A second isolated section for study is afforded in West Philadelphia, which has had all of its city water supply filtered since 1906 and where the typhoid rate has dropped to 5.9 per 100 000 in 1912. This section of the city is located west of the Schuylkill River, from which its water supply is taken, and has increased in population from 99 102 in 1896 to 267 840 in 1912, almost threefold. It is largely a residential section, and its water supply is entirely separate from the remainder of the city. Numerous asylums, hospitals, homes for the aged, etc., are located in West Philadelphia, and the mortality statistics are strongly influenced by this institutional factor, which is included in the rates computed.

When it is considered that the water supply of West Philadelphia is taken from a grossly polluted stream, and the people, in large part, pass daily into a district that has not had as good water, and that it has had its typhoid rate reduced from a high rate of 88.1 per 100 000 in 1903 to a rate of 5.9 per 100 000 in 1912, the capability of filtration works is at once apparent.

The time elapsed since the entire city water supply has been filtered is too short for any suggestion to be made as to what ratio the Mills-Reineke phenomenon, — as expressed by the Hazen theorem,* where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided, — will take for this city.

The total death-rate has on the average declined since the period 1862–70. The decline more than doubled during the decade 1901–1910, when the water supply was being improved, during which period the typhoid rate rose slightly. The total death-rate has since continued to decline, and the Health Department is striving to make it go still lower, but as to how much of the decrease in total mortality can be attributed to the better water supply, under the complex conditions which influence the death-rate in this city of 1 600 000 people, the writer frankly states he will not undertake to express an opinion. This is stated in no spirit of

* Sedgwick and McNutt, *Journal of Infectious Diseases*, Vol. 7, No. 4.

TABLE NO. 9.

CHANGES IN TOTAL AND TYPHOID MORTALITY RATES PER 100 000 POPULATION.

Period.	Total.	Decreases.	Typhoid.	Decreases.	Total less Typhoid.	Decrease from Previous Decade.	
				Philadelphia.			
1862–70	2 291.2	....	79.9	....	2 211.3	....	
1871–80	2 170.2	121.0	58.1	21.8	2 112.1	199.2	
1881–90	2 142.9	27.3	68.5	*10.4	2 074.4	37.7	
1891–00	2 018.7	24.2	44.6	23.9	1 974.1	100.1	
1901–10	1 792.2	226.5	45.2	* .6	1 747.0	227.1	Changing water supply.
1891/1900–1911	1 650.0	368.7	14.1	31.1	1 635.9	338.2	Compared with '91–'00.
1891/1900–1912	1 522.0	496.7	12.5	32.7	1 509.5	464.6	Compared with '91–'00.
				West Philadelphia.			
1892–97	2 463.8	....	33.6	....	2 430.2	....	Six-year period.
1898–03	2 447.7	16.1	64.8	431.2	2 382.9	47.3	Six-year period.
1904–06	2 264.7	199.1	52.5	12.3	2 212.2	170.7	Changing water supply.
1907–12	1 677.8	786.0	15.9	36.6	1 661.9	721.0	Compared with '98–'03.
1912	1 561.0	886.7	5.9	46.6	1 555.1	827.8	Compared with '98–'03.
				Twenty-First and Twenty-Second Wards.			
1894–02	1 559.0	....	35.2	....	1 523.8	....	Nine-year period.
1903	1 630.0	*71	62.5	*27.3	1 567.5	23.7	Changing water supply.
1904–12	1 490.0	69	23.6	11.6	1 466.4	56.4	Compared with '94–'02.
1912	1 323.0	230	35.1	.1	1 287.9	235.9	Compared with '94–'02.

* Increase.

criticism or attempt to dispute the Mills-Reincke phenomenon, and the facts here presented have been given only to show the very great difficulty in demonstrating it for Philadelphia.

West Philadelphia in one case shows a great decline in total mortality, and in practically all of the selected diseases, in its brief period of filtered water, but mortality rates of many diseases have been profoundly influenced by its institutional factor. Likewise, the twenty-first and twenty-second wards have experienced a decreased mortality rate with a fluctuating typhoid rate, due in large part, with but one exception, to other causes than water supply.

It is confidently expected that the death-rate of Philadelphia will be still further reduced from its too high level. It is believed that the water supply will be a factor in effecting that reduction, for the hygienic value of a good water supply is unquestioned. Even suspicion of the water has both a physiological and psychological effect: the former in that sufficient water will not be used for physiological needs; the latter in that the element of fear will exert a depressing effect and add to the harm done by the use of too little water.

It is believed that the facts set forth show that a large percentage of Philadelphia typhoid was from water infection and that a great reduction in the typhoid rate must be largely attributed to the filtration and improvement of the water supply. As to the other effects of the changed supply, we can safely await the outcome of the future.

PROPER CHARGE FOR FIRE PROTECTION SERVICE.

TOPICAL DISCUSSION.*

[*June, 1914.*]

Mr. W. E. Miller† (*by letter*). It would doubtless be impossible for anyone to successfully maintain that fire protection service should be furnished entirely free of special charge as though covered wholly by the public hydrant rentals or other earnings. Courts have held, and will probably continue to hold, that it is a special and valuable service for which the utility is entitled to compensation, — that is, if the utility demands it. The question is, How much can utilities reasonably and properly demand as annual rates for connections of specific sizes? In other words, How valuable is the service?

It is reported that a large number of the water plants of this country, including several privately owned works, are voluntarily furnishing such service free of special charge, apparently on the grounds that such service is of mutual benefit and that it is fire protection service and as such it is covered in the public hydrant rentals. Numerous other plants, both publicly and privately owned, are making a small, merely nominal annual service charge. Others are advocating rates that are quite substantial, if not high.

Some statistical information of interest in this connection, compiled from 55 answers received in reply to a circular letter sent by him to 75 representative city water departments and water companies scattered over the country, was presented in a paper by F. A. Raymond at the Denver convention of the International Association of Fire Engineers, held in 1912. In summarizing Mr. Raymond says:

"Briefly, these figures show that four fifths of the city works and one third to one half of the private works make no charge or only a nominal charge for fire connections; the rest charge all the way from $22.50 to $120 for various 6-in. connections, the com-

* Continued from page 67.

† Division Engineer, Railroad Commission of Wisconsin.

panies generally charging the higher figures. Such rates as \$105 and \$120, which two western cities charge for connections used only for fire purposes, together with the expense of installation, interest, etc., will go far toward balancing any saving in rates the ordinary property owner would make by installing standpipes or sprinklers, and in effect act to penalize him for reducing his hazard and the exposure to his neighbors. Of course the taxpayer must also pay his share of the general city fire protection."

The question becomes involved in every water-works rate case wherein the utility furnishes, or stands ready to furnish, service of this character. It also has to be met and settled irrespective of the rates for other classes of service when a water works begins to take on consumers in this class and circumstances do not call for a readjustment in the entire rate schedule.

The settlement of the question involves the determination of the principles on which the value of the service is to be measured. Some have advocated the establishment of rates for public water service to private fire lines on the basis of the probable cost to the owners of protected premises of supplying their own water service. Such an idea raises the question as to whether those same parties would or would not attempt, or expect to be able, to establish rates for each and every consumer in all classes on the same basis. The idea is certainly not in accord with the soundest principles of public utility rate-making or public policy.

Others have advocated the establishment of charges for private fire service on the basis of the saving produced to the owner of protected premises in his cost of insurance. Would it not be just as logical and reasonable to fix rates for each and every private consumer on the basis of the same proportion of the savings that might be shown to be obtained by him in one way or another? The application of the idea is very much in doubt.

Courts and commissions having jurisdiction in making rates for public utilities seem to have universally held that rate-making consists of a fair and equitable distribution of the total cost of furnishing the service rendered by the plant, including in such total cost the maintenance and depreciation of the property and a fair and equitable return to the investors on the value thereof.

This principle brings the question of proper charges for private

fire protection service down to the determination of the proportions of the various items in the total expense which can logically be apportioned to and charged against this particular class of service.

The primary apportionment to be made seems to be generally recognized as being between the public (or municipal hydrant) service on one hand, and the private (or all other) service on the other.

The municipal hydrant service includes the public fire protection furnished by the water works in conjunction with the services of the fire department. This form of fire protection is quite generally if not universally recognized as less efficient than automatic sprinkler systems, as is strongly evidenced by the difference in insurance rates for sprinklered and unsprinklered risks.

If a water works has the facilities for coping with fires in its territory in the ordinary and less efficient manner, that is, through hydrants, it certainly has the necessary facilities for fire-fighting through the more efficient apparatus except for the physical connections to the private apparatus. These connections involve an investment of money, either by the utility or by the owners of the premises served. They also require supervision and watching. If they be unmetered the utility is, as has been so widely shown by experience, in danger of suffering through the misuse and abuse of the service; that is, through the secret use of large quantities of water for purposes other than quenching fires.

If private fire service connections be unmetered, they require close inspections and tests. If metered, they involve meter expenses and a meter reading cost.

The writer's view is that the public hydrant service should, in general, bear the fire protection portion of all expenses of the plant up to the points of beginning of the private fire-service connections, for the reason that if the water supply and pump and pipe line capacities are adequate for hydrant service they are certainly adequate for a more efficient method of fire fighting.

It has been assumed, in the foregoing statements, that the private fire-service connections are equipped with reliable means for at all times maintaining control over the flow of water through them. Experience has shown that such control is not secured by

merely installing an ordinary manually operated gate valve on the line in such proximity to the building protected that flames from the building or a falling wall render the valve inaccessible at a critical moment.

Why not profit by the sad and costly experiences of the past and provide against loss of control of the water supply to and through such connections? Charging large annual rates or fees for inadequately protected service connections will not do it. The service charges to be made are more properly commensurate with the facilities provided than with the dangers existing through lack of proper provision against them. This protection against the dangers can be provided in more ways than one.

Nothing said herein should be understood as implying a belief on the part of the writer in depriving any utility of any just revenue, for such idea is farthest from his intent. It is merely a question as to how any given amount of total revenue should be distributed over all the service and consumers, public and private. It has seemed impossible to find any but a purely arbitrary basis upon which to apportion to private fire-protection services any of the investment charges involved by the pumping plant or system of mains which, so far as any fire-protection service whatever is concerned, is necessary for the hydrant service irrespective of whether the more efficient sprinkler service is furnished or not. So far as operating expenses are concerned, the charges against private fire protection should be limited to the inspection and maintenance costs involved by these connections and to output charges for water used through them for purposes other than fire fighting. The amount of water so used can and should be known from a meter on each line. The capital or investment charges included in rates for this class of service should be limited to the utility's investment in the connections.

In the writer's judgment the proper rates for private fire-protection service are relatively low as compared with certain rates that have been advocated.

SOME PROBLEMS IN THE DESIGN OF SMALL WATER-WORKS SYSTEMS.

BY WILLIAM S. JOHNSON.

[Read March [illegible].]

It is the lot of most engineers and water-works superintendents to have to deal almost exclusively with small things — to have to solve innumerable petty problems — and solve them, generally, without the assistance of books.

Most of the available printed information relates to the large things in engineering. The engineer or superintendent reads with great interest the accounts of the New York water supply, the Wachusett Reservoir, or the Panama Canal, and, perhaps dreams of similar accomplishments, but he is apt to do the small things which are likely to constitute his lifework in the way he has always done them or in the way in which he has seen some one else do them. If, perchance, he makes some improvement in the methods, he is likely to keep it to himself, thinking it, perhaps, too small to interest the Water Works Association or the readers of engineering periodicals, who have been surfeited with the great engineering feats; and the next man who has the same problem to solve has to solve it independently.

One does not realize the comparative dearth of reliable information relating to small things, such things as are likely to come up in the average engineer's practice, until he begins to search for it in the books. He will find details of the greatest dams which have been constructed and of the great aqueducts, but very little that will help him in designing a twenty-foot dam or a system of small water pipes. Page after page is devoted to the things which not one engineer in one thousand ever has an opportunity to design, but with little or no space for that which every engineer is almost certain at some time to want to know. They may be things which can be worked out without assistance, but the experience of others is likely to save many mistakes and is almost certain to

save somebody considerable expense. There is as much opportunity for good engineering in the construction of a small water-works system as in the construction of the Panama Canal. That is, the problems are as numerous and as complicated, and the pocketbook of the man who helps pay the bills for the small water-works system will be more affected by the good or poor engineering in such a system than that of the individual who helps pay the bills for the Panama Canal.

The same can be said of the management. A good superintendent can do more to reduce the water rates in a town of three thousand than can the superintendent in a large city. The great trouble is that there is no glory in cutting off five hundred dollars from the cost of construction of the fifty-thousand-dollar water-works system or in saving two hundred dollars in maintenance by good management, even though the water rates may be kept down thereby, while in the working out of some problem in a large undertaking in which there is great public interest, there is much glory even though the proportionate saving may be less than in the small system.

Not only does the engineer or the superintendent of a small system get no glory, but he is likely to get no adequate compensation. The difference in salary between the water-works superintendent under whom the expenses of the department are $10 000 and the one who reduces them to $8 000 is not generally noticeable, and the difference in the compensation between the engineer who plans works for $60 000 and the one who gets the same results for $50 000 is likely to be in favor of the former, for the smaller the total cost, the less the fee of the engineer is likely to be.

In the state of Massachusetts there are 215 water-supply systems, and of these 152 were installed before the population of the towns they supply was five thousand, and 111, or more than half, are now still supplying towns of less than five thousand. In fact, the opportunity seldom comes to design a complete system of works for a large community, the larger systems being extensions of the systems designed for the small town. As there are only four towns in Massachusetts having a population of more than three thousand which remain unsupplied with water, it is likely that, in this state at least, the problems arising in small systems will

be more numerous than the problems connected with the larger systems, although perhaps not so interesting to any but those immediately affected.

The importance of the small water-works problems is indicated in the following table giving the number of towns of given populations in Massachusetts having and not having public-water supplies.

Population (1910)	Number of Places Having Public Water Supplies.	Number of Places *Not* Having Public Water Supplies.
Under 1 000	6	80
1 000–1 499	21	29
1 500–1 999	13	20
2 000–2 499	21	12
2 500–2 999	12	2
3 000–3 499	8	1
3 500–3 999	5	2
4 000–4 499	7	1
4 500–4 999	10	..
Above 5 000	103	..
Total	206	147

In my practice it has been my lot to put in a number of small water-works plants, and it has surprised me to see how easy it is to save ten per cent. of the cost of construction by a thorough study of the problem. I have also found that many problems over which I have worked have been solved by others who have kept the results to themselves, not because of unwillingness to part with the information, but because the matter seemed too small to be of general interest. It is with a view of encouraging the discussion of the problems connected with small water-works installations, as well as to give a few of the results of my own experience, that this paper is presented. The problems are numerous, and it is possible to discuss here only a few of them, selecting those which are likely to have the greatest influence on the cost of the plant.

TIME FOR WHICH WORKS SHOULD BE BUILT.

The first problem which presents itself in designing a water-works system is the determination of the size of the plant to be

constructed, and this depends, in the first place, upon the time for which the works should be built. A distinction should be made between the time for which works should be built and the time for which they should be designed.

The works should be designed for a long time in the future. That is, the probable requirements of the future should be carefully studied and the means of fulfilling these requirements considered and in a rough way determined. But the design should provide for as little immediate construction as is possible except where the cost of extensions or increased capacity will be much more than the cost of doing the work in the beginning.

There is no doubt that many water-supply systems have been constructed to serve too long a period, and that money has been wasted in this way.

Many a water-works superintendent has portions of his plant which he wishes had been designed for a shorter period, so that it might now be rebuilt to better serve the present requirements.

To build works for a long time in the future assumes a power of prophecy which most of us do not possess. In the first place, it is beyond the power of man to foretell what is going to happen to any community and especially to the small town. A hitherto prosperous community may no longer prosper, or the population may advance by leaps and bounds, making the plant designed for a slow-growing town out of date in a short time.

To illustrate this, Fig. 1 has been prepared, which shows graphically what has happened in several places where water supplies have been introduced. The diagram shows the population for each census period before and after the introduction of water. The information at the left of the heavy line was available at the time the works were introduced, and in no case was there anything in the past growth to indicate that the future was to be what it actually was, as is shown to the right of the heavy line. Of course these are exceptional cases, for in the great majority of towns the past growth and the growth of other towns similarly situated give a fair indication of what may be expected in the future.

Besides the uncertainty as to what may happen to the town as a whole, there is the uncertainty as to the direction which growth

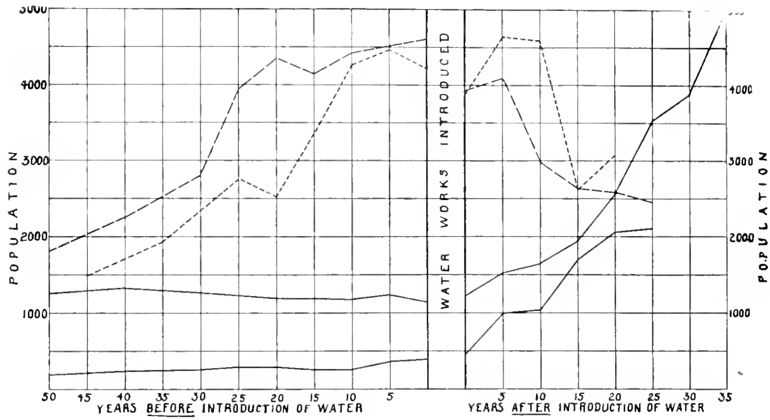


FIG. 1.

may take within the town. There are numerous cases where what promised to be the center of the business district of the town has become merely a suburb of another unthought-of center.

Advancements in the art of water-supply engineering are very rapid, and these are likely to make certain parts of the plant obsolete within a comparatively few years, so that they must be abandoned, or ought to be abandoned.

The rapid changes in the requirements of the public which uses the water is another factor making it unwise to build for too long a time. The standards of purity of twenty years ago do not at all meet the present requirements for clear and colorless as well as safe water. Many a supply which was considered good a few years ago is now considered unfit for use. A distributing reservoir which gave a very satisfactory pressure is now supplanted by a higher reservoir to meet the modern requirements for fire protection.

The changes which may be necessary or desirable in the sources of supply are indicated by the fact that of 163 sources of public supply in use in Massachusetts twenty years ago, 37 have been abandoned. Some of these were abandoned for larger sources, but most of them because the supply was unsatisfactory for some other reason.

Another reason why works should not be constructed for too

long a time in the future, is that it is wrong to call upon one generation to pay for the plant which another generation is to use, and especially as the next generation is likely to be much better served by modern, up-to-date works constructed to meet the requirements that then exist.

It is obvious that no part of the plant should be built to serve a longer period than the life of that particular portion, and this, in the more perishable parts of the plant, may well form one limit, but most of the plant has a duration of life well beyond the period for which the works should be built.

What has been said concerning the desirability of planning for the future but building for the present applies particularly to the source of supply. In developing the sources of supply, it certainly is not necessary or wise to develop in the beginning works which will supply the maximum requirements under the most unfavorable conditions for many years in the future.

The putting in of a water-works plant is not like building a bridge, for in the latter case the structure must be built to take the greatest load which it may have to carry, and this load may come at any time. If the bridge fails, the results are disastrous. In developing a water supply the greatest load will come at some time in the future when the consumption has greatly increased and when an unusually dry year occurs. When it comes, however, it will give sufficient warning so that extensions may be made to meet the emergency, and in case of necessity restrictions may be placed on the use of the water, curtailing the amount used for unnecessary purposes. While such restrictions are not desirable, it is obviously better to plan on resorting to them in great emergencies than to expend large sums of money in preparing for such emergencies which may never arise during the life of the works.

We are told that the greatest drought, of which we have any record, occurred about ninety years ago, and if all the water works which have been constructed since that time were built to supply water during such a drought there would have been an absolute waste of many dollars, for it has never occurred again.

Many times considerable sums can be saved in the construction of water works by developing sources of supply which are

known to be inadequate in a very dry season, with plans prepared, however, for the installation of an additional supply when required. A recent instance of this is the construction of the works of the Deerfield Fire District. A well was constructed from which a gravity supply could be obtained, adequate during most of the year but very limited in quantity during a dry season. Advantage was taken of the fact that during the first years of the works the consumption would be small and also of the chances that a dry season might not occur, and the auxiliary pumping supply which had been planned was omitted. The well alone supplied the town for two or three years before it was necessary to construct the auxiliary pumping station by which the gravity supply was to be supplemented, and had the exceptionally dry years not then come, the time would have been much longer. This auxiliary supply was put in when needed at no greater cost than if it had been installed in the beginning, and the interest on the investment for three years was saved.

In a recent report to the city of North Adams, Prof. G. F. Swain well expresses this idea. "In seeking a source of water supply, therefore, the aim should be to secure a source which is adequate for the near future and which is sufficiently flexible and possessed of such potentialities that, as the demand increases, the system may be extended from time to time. It will manifestly conduce to economy if the system can be extended as the need is felt, rather than if the distant future has to be provided for at the outset."

Experience indicates that the time for which the durable portions of small water-works plants, except the source of supply, should be constructed is about thirty years, the time ordinarily allowed for the payment of the cost of the works. Much of the plant will undoubtedly serve a much longer time, but if it is outgrown the works have been paid for by the generation which used them and our successors have no reason to complain if they have to rebuild.

Perhaps it should be said, however, that building water works for the immediate future may not always bring glory to the engineer; the public is likely to forget, if they ever know, that the works were designed to be outgrown in a given time, and the engineer

may be severely criticised for his poor judgment and lack of foresight. On the other hand, the builders of the Roman aqueduct have received no end of praise because they built so unnecessarily well as to have their work stand for centuries after its usefulness had passed.

CAPACITY OF THE PLANT.

The capacity of the distributing system is determined, in the case of the small town, by the fire protection requirements solely. One good effective fire stream will use water at as great a rate as will the ordinary town of five thousand inhabitants during the hours of maximum draft; and a distributing system, therefore, designed to give adequate fire protection will at all times give an ample supply for domestic purposes. The capacity of the source, however, is determined not by the demand for fire protection, which at most lasts but a few hours, but by the more constant demand for domestic purposes. An exception to this occurs in the case of the system which is not provided with sufficient reservoir capacity to store the amount of water required for the greatest conflagration when it is necessary to have a source of supply which will yield a large quantity of water in a short time.

The quantity of water which will be drawn from the sources of supply depends upon the population to be supplied, the character of the residences supplied, the care taken to prevent leaks and other wastes, and the use of water for manufacturing or mechanical purposes.

Attempts to estimate closely the future population are in nearly all cases very unsatisfactory. There are so many circumstances which may arise in any town — and especially the small town — which will have a great influence upon the population and which cannot be foretold, that estimates are likely to be of comparatively little value. The construction of a large factory may double the population of a town of three thousand within a few years, and, on the other hand, the loss of a large industry may cause a loss of half the population.

Illustrations have already been given of cases where the popula-

tion has increased or decreased at a rate which could not possibly have been foretold. However, some estimate must be made in order to arrive at the quantity of water likely to be required, and undoubtedly the best way to do this is to study the past growth of the town in question, together with the growth of other towns similarly situated which are now larger than the town being studied. A good way to make such a study is illustrated in Fig. 2. A group of towns of larger population than the one in question

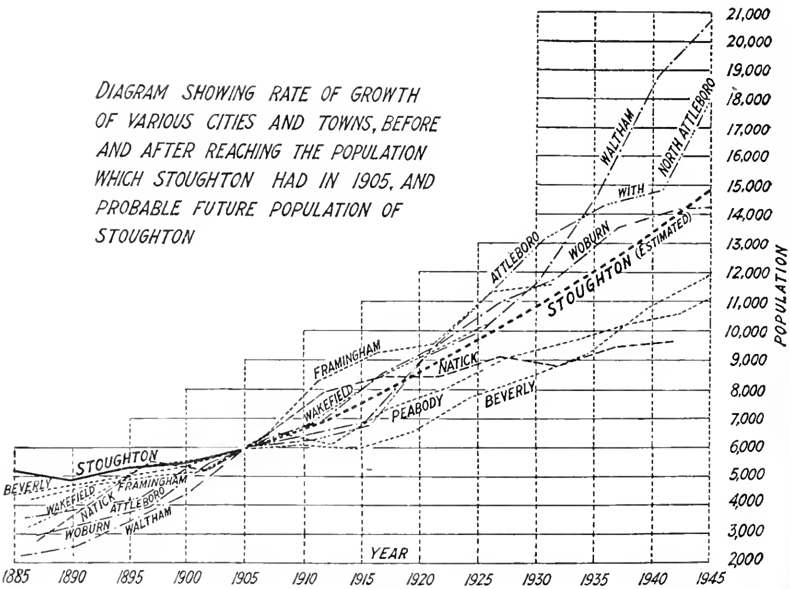


FIG. 2.

but which have been somewhat similarly situated with respect to railroad facilities, proximity to larger towns, facilities for manufacturing, etc., is selected. The population, by census periods, of each of these towns is then plotted in such a way that the curves of population will all meet at the point which represents the present population of the town in question. This shows in a graphical way what may be expected if the town in question grows at the same rate that any one of the other towns grew after it had reached

the present population of the town being studied. A study of such a diagram with a thorough knowledge of the local conditions in each of the places considered will enable one to make as good an estimate as is possible.

The quantity of water which will be drawn from the sources by a given population depends very largely upon the care taken to prevent leaks and other wastes and the use of water by manufacturers or other large consumers.

The efforts which are made to prevent leaks and other wastes have a great effect upon the per-capita consumption. Unfortunately experience has shown that while it is possible by rigid inspection and by testing to make the water system practically water tight in the beginning, it is not safe to count on continued efforts in this direction, and it must be assumed, in designing works, that at least average conditions will prevail.

The quantity of water used by manufacturers or for mechanical purposes is, many times, — especially in a small community, — a very large proportion of the total use. While these uses cannot be considered domestic uses, it is generally considered good policy to supply such customers. Sometimes the quantity required for these purposes can be known in advance and can be allowed for in designing the works, but in other cases it is necessary to include the possibility of such uses in making the final guess as to the quantity of water which will be required.

The increasing per-capita consumption of water is also something which should be considered. The causes for this increase have been frequently enumerated, and they are largely what may be designated as legitimate. The number of plumbing fixtures in houses and the greater quantity of water required for each fixture are among the chief reasons. Although for many years prophecies have been made that this increase would stop, it still continues, and water-works systems must be constructed to meet this demand for an increased quantity of water.

A future per-capita domestic consumption of from 75 to 100 gal. per day for ordinary small towns does not seem unlikely, and in the case of towns having large estates and a large area of well-kept lawns the consumption may be much larger.

In estimating the future consumption of water there is danger of

counting on what might be or should be, rather than figuring on what experience teaches is likely to be.

The average daily consumption of water per inhabitant in seventeen Massachusetts towns having a population of less than 3 000, excluding towns used as summer resorts, is 40 gal. The maximum in the above group is 62 gal. In 18 towns having a population of from 3 000 to 6 000 the average consumption is 50 gal., with a maximum of 102 gal. The consumption in 9 small towns used as summer resorts is 96 gal., with a maximum of 185 gal. These figures are averages for the year, and are much exceeded during certain months.

REQUIREMENTS FOR FIRE PROTECTION.

The requirements for fire protection are responsible for a large proportion of the cost of the small water-works system. In fact, excepting at the source of supply, as far as construction is concerned the furnishing of water for domestic purposes is only incidental. The fire protection requirements determine the pressure to be maintained, the size of the distributing reservoir, the sizes of the street mains, and, in some instances, the size of the pumping plant. These portions of the plant could be made much smaller and much less expensive were it not for the need for fire protection.

Messrs. Metcalf, Kuichling, and Hawley, in a paper before the American Water Works Association,* state that "the cost of the portion of the water-works plant involved by fire protection probably constitutes from 60 to 80 per cent. of the entire cost of the physical property in the case of communities having less than five thousand population." This is undoubtedly true except in those places where it is necessary, in order to secure water of sufficient purity for domestic purposes, to go to a large expense in obtaining it or in its purification.

It is certain that the cost of furnishing fire protection constitutes such a large proportion of the total cost of the plant that every effort should be made to make this portion of the plant as efficient as possible, getting the greatest possible return for the money. If the reservoir is of large capacity but the pipes are small, much

* Proceedings, 1911, p. 55.

of the cost of the reservoir is practically wasted. If the hydrants are not properly spaced, the advantages of large distributing mains are to a considerable extent lost.

The representatives of the insurance companies have taken the lead in making the water-works systems more efficient for fire protection, and the designing engineers and superintendents have unfortunately acted as a drag and in many cases have prevented the expenditures of comparatively small amounts of money which were needed to keep the large sums which have been spent from being practically wasted.

The fire protection feature in small water-works systems is of comparatively recent origin, and many of the earlier systems installed in small places were constructed for domestic service only. The importance of protection from fire and the inducements of lower insurance rates have created a demand for better fire-fighting facilities, so that this function of a small water-works system is now almost as important as the furnishing of water for domestic purposes.

Before the advent of the trained insurance engineer, the requirements of the companies were not always as consistent as they generally are now. In one case I have been asked to change the size of the main pipe from the standpipe to the village from 12 in. to 18 in., because we "don't like to have the main from the standpipe less than 18 in."; and this request was made without any information in regard to the pressure or the distance to the village. On the other hand, I found a village which boasted one hydrant. and the insurance rates on all property within 500 ft. were reduced on this account. The one hydrant was supplied from a 2-in. pipe which brought water to a neighboring drinking fountain under a static head of 40 ft., and was of little more value as a protection from fire than the town pump.

Now, the requirements of the insurance companies are likely to be reasonable, or at least there are good reasons for the requirements, and one of the duties of the designer of the water-works system is to balance these reasons with other considerations, with which he should be familiar, but to which insurance men are not expected to give so much weight.

In a small town it is usually necessary to depend entirely on

hydrant streams without the use of steamers, and it is essential, therefore, that the works, either by themselves or assisted by some outside source, should furnish both the requisite quantity of water and the proper pressure with which to fight the greatest conflagration which is likely to occur, and to do this under the most unfavorable conditions in regard to domestic consumption and quantity of water in reservoir or standpipe.

The standard fire stream is now considered to be that thrown by a $1\frac{1}{8}$ in. smooth nozzle discharging 250 gal. per minute, and it is generally considered by the insurance engineer that a hose stream which does not throw 200 gal. per minute is not a good stream. There are many cases, however, when smaller streams throwing from 150 to 175 gal. per minute would furnish a reasonable protection, and all that a town would be justified in providing in some districts. It should always be remembered that in the outlying sections of small towns any fire which gets sufficient headway in the ordinary building, so that it cannot be conquered with two streams of 150 to 175 gal. each, is not likely to leave much of value if it is extinguished by using six streams. In such cases the value of the water is chiefly in saving adjacent buildings, and for this purpose even small streams are of great value.

For streets in a district where the houses are small and occupy comparatively large lots, with no prospect of any considerable increase in density of population, and where extensions of the mains are not likely, a hydrant which will furnish 300 gal. per minute under a suitable head to any building in the territory supposed to be covered by this hydrant will be good fire protection. More is desirable, but the advantages are not sufficiently great to warrant the expense of larger mains to secure it.

In a district where the houses are nearer together but containing no business blocks, apartment houses, or other large buildings, it should be possible to get 500 or 600 gal. per minute at any point.

Where there are business blocks and other large buildings, and where the buildings are very close together, as they frequently are in the center of a small village, it should be possible to get 1 000 gal. per minute. When there are factories or other special fire risks, a much larger quantity may e necessary, and a special study should be made of each case.

The pressure required at the hydrants while the hydrants are being used should be great enough to force the water through the greatest length of hose which will be used, and throw it to a sufficient height to cover any building. The hydrant spacing and the pressure should, therefore, bear some relation to each other. The following table, taken from a paper by Mr. E. V. French,* gives the limit of a good, efficient fire stream with different lengths of good cotton, rubber-lined hose, with a constant pressure of 60 lb. at the hydrant, and also the amount of water which would be discharged.

ONE $1\frac{1}{8}$-IN. STREAM FLOWING FROM A SMOOTH-BORE NOZZLE.

Length of Hose.	Limit of Height, with Moderate Wind, as a Good, Effective Fire Stream.	Gallons per Minute Flowing.
100	67	250
200	59	222
300	52	206
400	44	188
500	40	178
700	33	158
1 000	25	140

The table shows the importance of having hydrants near the buildings to be protected. Unless the hydrants are near enough to furnish water at the fire under a good pressure, the expense of large pipes and a high reservoir is largely wasted. The cost of a two-way hydrant in place is about $40, and in the ordinary distribution system about 8 hydrants are required per mile of street main to keep the hydrants within 250 ft. of every building in the territory covered; so that the expense of the hydrants is very small compared with the expense incurred in other parts of the system to obtain efficient fire protection; and the saving of two or three hydrants is poor economy if the efficiency of the other portions of the system is wasted thereby. There is an opportunity for the exercise of judgment in the location of the hydrants, and they should not be placed, as is the case in many towns, to meet the wishes of the influential property owners. In general,

* JOURNAL N. E. W. W. A., *25*, 249.

hydrants should not be more than five hundred feet apart in the outlying sections. In the more closely built-up sections they should be so spaced as to make it possible to get the number of streams which are considered necessary at any particular point with the use of not more than about three hundred feet of hose for each stream. This figure may be modified, however, if the pressure is unusually high, and should be if the pressure is unusually low.

The minimum pressure desirable for good fire protection with hydrants spaced as suggested is about 50 lb. per sq. in. at the hydrants when they are in use. This pressure will give, with 300 ft. of best quality hose and $1\frac{1}{8}$-in. nozzle, a stream of 185 gal. per minute, which can be thrown to a height of 44 ft. With 200 ft. of hose the quantity thrown would be about 200 gal. per minute, and the height would be increased to 50 ft. There are cases where in the higher sections of the town these pressures are almost impossible, and in such places the hydrants should be so located as to require as little hose as possible.

In the case of thickly built-up villages, the pressure should be 60 lb. per sq. in. at the hydrant when the water is being drawn at the maximum rate. This pressure will give a stream of more than 200 gal. per minute with 300 ft. of hose, and with 200 ft. of hose will send 222 gal. per minute to a height of about 60 ft.

The size of the mains depends entirely on the requirements determined on to give fire-fighting facilities, and on the head available. When these are known, the system can readily be designed. Generally, however, the head which can be secured is not fixed but can be made whatever is desired by putting in additional expense, and the determination of the most economical arrangement of height of reservoir, size of pipes, and spacing of hydrants is a matter for careful study.

The rule adopted in many places to put in no street main less than 6 in. in diameter in most cases works out properly, but there is no excuse for it as an arbitrary rule. A short street will many times be better served with a 4-in. pipe than other streets in the same system with 6-in. mains, and the money saved by using the smaller pipe could well be expended in strengthening those parts of the system which are weaker. The standard should be the quantity of water the pipe will deliver and the head under

which it delivers this amount. If a 4-in. pipe will do this satisfactorily there is no good reason why it should not be used.

The loss of head due to friction in a 6-in. pipe which has been in the ground for some time, when water is being drawn at the rate of 300 gal. per minute, is about 10 ft. per 1 000 ft. of length, and this figure, together with the required pressure at the hydrant of 50 lb. per sq. in., should in general determine the allowable length of 6-in. pipe as a dead end.

PUMPING PLANTS.

The development of the oil and gasoline engines has done much to make water-works systems for small places financially possible. When the only feasible pumping machinery was the steam pump, the cost of installation of pumps and boilers, the cost of the pumping station to house them, and the cost of maintaining the plant, made a water supply practically out of the question unless a gravity supply could be secured. With the new form of engine, however, the conditions are quite different. The cost of the machinery has been greatly reduced, the cost of the station is much less, and the cost of operating is reduced to a minimum on account of the fact that with oil or gasoline there is no consumption of fuel except while work is being done, while with a steam plant a large proportion of the coal is used in banking the fires and getting up steam.

Electricity is also becoming an important factor in connection with small pumping plants, although the cost of current is so great that there are few places where oil or gasoline are not more economical, except for auxiliary plants used only occasionally.

Pumps should usually be designed for the greatest economy in doing the work which they are called upon to do regularly in supplying the domestic needs of the town without regard to their use for five protection purposes. It is seldom feasible in the small system to have pumps of sufficient capacity to be of very great value in case of fire, and dependence for fire protection should be placed on water stored in a reservoir or large standpipe or tank, or on some connection with factory pumps through which a large supply of water can be quickly secured. With increased size of

TABLE 1.

Town.	Population. (1910.)	Date of Introduction of Works.	Average Daily Consumption. (Gallons).	Number of Pumps.	Capacity of Each Pump. (Gals. per 24 Hrs.)	Hours Required to Pump Average Daily Consumption.		Kind of Power Used.
						With Whole Plant.	With One Unit.	
Orange	5 282	1873	161 000	2	800 000	2.4	4.8	Water and steam
Lincoln	1 175	1874	221 000	2	750 000	3.0	7.1	Steam
					1 000 000	...	5.3	
Nantucket	2 962	1878	233 000	5	400 000	2.5	14.0	Steam, gasoline and oil
					400 000	...	14.0	
					600 000	...	9.3	
					600 000	...	9.3	
					250 000	...	22.4	
Mansfield	5 183	1883	569 000	2	720 000	9.5	19.0	Steam
Wellesley	5 412	1884	374 000	2	1 000 000	3.7	9.0	Steam
					1 440 000	...	6.2	
Franklin	5 641	1884	296 000	4	1 000 000	1.3	7.1	Steam
					1 500 000	...	4.7	
					1 500 000	...	4.7	
					1 500 000	...	4.7	
Sharon	2 310	1885	149 000	2	350 000	2.7	10.2	Steam
					1 000 000	...	3.6	
Kingston	2 445	1886	......	2	300 000	...	...	Water and electricity
Grafton	5 705	1886	114 000	2	500 000	1.8	5.5	Steam
					1 000 000	...	2.7	
Easton	5 139	1887	135 000	2	700 000	2.3	4.6	Steam
Tisbury	1 196	1887	......	2	1 000 000	...	...	Steam
Ayer	2 797	1887	162 000	2	500 000	2.6	7.8	Water and steam
					1 000 000	...	3.9	
Needham	5 026	1890	356 000	3	750 000	2.8	11.4	Steam
					750 000	...	11.4	
					1 500 000	...	5.7	

Foxborough	3 863	1891	234 000	2	720 000	3.9	7.8	Steam
Reading	5 818	1891	234 000	2	900 000	3.1	6.2	Steam and electricity
Provincetown	4 369	1893	212 000	2	1 000 000	2.5	5.1	Steam
North Brookfield	3 075	1893	224 000	2	1 000 000	2.7	5.4	Electricity
Onset	....	1894	71 000	2	500 000	1.9	3.4	Steam
					400 000	...	4.3	
Fairhaven	5 122	1894	400 000	4	500 000	2.1	19.2	Steam
					840 000	...	11.4	
					1 500 000	...	6.4	
					1 700 000	...	5.6	
Longmeadow	1 084	1895	93 000	2	720 000	1.6	3.1	Oil and steam
					648 000	...	3.4	
Millbury	4 740	1895	190 000	2	750,000	2.7	6.1	Steam
					1 000 000	...	4.6	
Rutland	1 743	1896	99 000	2	250 000	1.9	9.5	Steam
					1 000 000	...	2.4	
Weston	2 106	1896	106 000	4	150 000	2.0	16.9	Steam and electricity
					300 000	...	8.5	
					350 000	...	7.3	
					500 000	...	5.1	
Walpole	4 892	1896	538 000	2	1 500 000	4.3	8.6	Steam
Winchendon	5 678	1896	182 000	2	1 000 000	1.7	4.4	Steam and electricity
					1 500 000	...	2.9	
Billerica	2 789	1898	165 000	2	960 000	2.1	4.1	Steam
North Andover	5 529	1898	261 000	2	1 500 000	2.1	4.2	Steam
Shirley	2 139	1903	64 000	1	120 000	12.8	12.8	Power from mill
Merrimac	2 202	1904	88 000	2	1 000 000	0.9	2.1	Steam
					1 250 000	...	1.7	
Edgartown	1 191	1906	61 000	2	421 200	1.8	3.5	Oil
Oxford	3 361	1906	......	2	720 000	...	...	Oil
Dracut	3 461	1906	53 000	2	288 000	2.2	4.4	Gasoline
North Chelmsford	5 010	1907	70 000	2	288 000	2.9	5.8	Electricity
Wrentham	1 743	1908	96 000	2	360 000	3.2	6.4	Oil
Westford	2 851	1908	71 000	1	500 000	3.4	3.1	Electricity

TABLE 1.—*Continued.*

Town.	Population. (1910.)	Date of Introduction of Works.	Average Daily Consumption. (Gallons).	Number of Pumps.	Capacity of Each Pump. (Gals. per 24 Hrs.)	Hours Required to Pump Average Daily Consumption.		Kind of Power Used.
						With Whole Plant.	With One Unit.	
Marion	1 460	1908	115 000	2	1 008 000	1.4	2.7	Oil
Bedford	1 231	1909	30 000	2	360 000	1.0	2.0	Gasoline
East Brookfield	....	1909	......	2	125 000	...	...	Oil
Pepperell	2 953	1909	110 000	2	360 000	3.7	7.3	Oil
Blandford	717	1909	......	1	108 000	...	...	Gasoline
Douglass	2 152	1910	......	2	350 000	...	...	Electricity
					187 000	...	...	
Dudley	4 267	1910	124 000	2	360 000	4.1	8.3	Electricity
Medway	2 696	1911	......	2	504 000	...	...	Oil
Leicester, Cherry Valley and Rochdale	....	1911	......	2	288 000	...	...	Oil
Ashland	1 682	1911	20 000	2	216 000	1.1	2.2	Oil
Norton	2 544	1912	......	2	432 000	...	...	Oil
Barnstable	4 676	1912	75 000	1	1 000 000	1.8	1.8	Oil
Littleton	1 229	1912	41 000	1	350 000	2.8	2.8	Oil
Acton	2 136	1912	......	2	432 000	...	...	Oil
West Groton	....	1912	18 000	1	120 000	3.6	3.6	Gasoline
West Brookfield	1 327	1913	......	1	360 000	...	...	Electricity
Mattapoisett	1 233	1913	......	2	360 000	...	...	Oil

pumps it is necessary to have a larger force main, a larger suction pipe, more wells, if the supply is taken from driven wells; in fact, a considerable portion of the plant must be increased in size and made more expensive in order to operate large pumps. It is generally an expensive mistake to the design the pumps for anything but the domestic service.

Large pumps are somewhat more efficient than small ones, and if an attendant remains at the station while the pumps are in operation there is a saving in the shorter hours required with the large pump. With the oil engine, however, or with electricity, constant attendance is unnecessary, especially in the case of the smaller plants.

Pumping machinery should always be provided in duplicate, and works, although designed to run most economically when one unit is in operation, can be operated if necessary at double capacity with a somewhat reduced efficiency. A plant designed for a community which will use from 100 000 to 150 000 gal. per day, should generally have a capacity of about 250 gal. per minute for each unit. This would mean the operation of one of the pumps for from six to ten hours each day. Such a plant would give two large fire streams, in case of fire, by starting both of the pumps.

Many of the pumping plants are undoubtedly of too large capacity for economy, and the tendency is in recent years to make them smaller — especially when the power used is some form of explosive engine.

Table 1 gives the capacity of the pumps in many of the small plants in Massachusetts, as compared with the average daily consumption. In using the table it should be remembered that some of the plants have only been recently installed and the consumption has not yet become normal, and that in other places the summer consumption is much in excess of the average daily consumption. The towns are arranged in order of the date of introduction of works, in order that the effect of the newness of the plant may be more easily discounted.

DISTRIBUTING RESERVOIR.

The design of the distributing reservoir is affected chiefly by the topography, the requirements for fire protection, and by the

facilities for pumping. In a much less degree it is affected by the water consumption.

The effect of the topography upon the design is generally to change the reservoir from what is desirable to what is feasible. In a comparatively flat country it is practically impossible to store as much water at as great an elevation as is desirable, and in such cases the distributing reservoir must be cut down, and other portions of the system must be designed to do the work which should properly be done by the distributing reservoir. For example, in a perfectly flat country where a high standpipe is the only feasible form of reservoir, the reservoir at most will only be a means of making it possible to pump for a few hours each day, and will furnish enough water to supply the hydrants until water can be pumped into the mains. In such a case it is necessary to provide pumping capacity either at the pumping station or by connection with fire pumps in some factory sufficient to furnish all the water which will be required for fire protection, and, as the pressure in such a system will necessarily be lower than is desirable, valves may have to be provided so that the pressure can be increased over that furnished by a full standpipe.

When the topography is such that it is feasible to build a reservoir of any desired size and any height, the design is dependent almost entirely upon the requirements for fire protection. The pressure furnished from the reservoir should be such as to give the required quantity of water at the proper pressure for fighting fires, and as this depends also on the size of the pipes, the pipe sizes and the reservoir pressure have to be considered together. The cost of pumping the water must also be considered. Generally it is found that the most economical static pressure from the reservoir at the point where there is likely to be the greatest demand for water is from 80 to 100 lb., depending to a large extent upon the distance from the reservoir to the center of distribution.

The maximum desirable pressure is a matter on which there is much disagreement, but the limit is constantly being extended. If it should prove to be more economical to have a system where the pressures run up to 150 lb., there would seem to be no good reason why this should not be done in a new system of water

works, and it would be likely to prove much more satisfactory than to maintain two levels.

In 86 small towns in Massachusetts the average static pressure in the central portion of the town is 79 lb. per sq. in. Nine of these towns have pressures of less than 50 lb.; 33 have pressures of from 50 to 75 lb.; 31, from 75 to 100 lb.; and in 13 the pressure is more than 100 lb.

The reservoir should be, if feasible, large enough to hold at the required elevation, in addition to the domestic supply for twenty-four hours, a sufficient quantity of water with which to fight any fire which is likely to occur. A fire in the built-up portion of a village may take about 1 000 gal. per minute or 60 000 gal. per hour. In general, the time during which this quantity will be required will not be more than from two to four hours. Applying this rule to the ordinary town with no large fire risks, the capacity of the reservoir or standpipe should be from 300 000 to 400 000 gal. During the time in which the water is being drawn from the reservoir it will generally be possible to start the pumps, which will add a certain amount of water, and if there are connections with fire pumps in factories these can also be brought into use.

The practice in Massachusetts is shown in Table 2, which gives such statistics as I have been able to get together for the smaller towns.

The capacity of the reservoir or standpipe as given in the table is the total capacity, and in the case of tall standpipes includes much water which is of little use in case of fire on account of the low pressure near the bottom of the standpipe.

I do not propose to discuss the relative merits of the steel standpipe and the reinforced concrete tank. Personally, I have no objection whatever to the use of the steel standpipe other than it is a blot on the landscape. In this respect also the concrete is not always superior to steel, for a leaky concrete reservoir is no ornament, and many of the concrete structures do leak. It seems to be largely a question of economy, keeping in mind the cost of maintaining the steel standpipe in repair but not making the mistake of assuming that the durability of the concrete will make the concrete tank good for all time, for the usefulness of any tank is likely to be passed by the time that a steel tank would be worn out.

TABLE 2.

Town.	Population. (1910.)	Date of Introduction of Works.	Average Daily Consumption. (Gallons.)	Capacity of Standpipe or Reservoir. (Gallons.)	Number of Days' Supply in Reservoir or Standpipe.	Quantity Remaining after Drawing One Day's Consumption.	Number of 250-Gallon per Minute Streams which could be Supplied for One Hour from Quantity in Preceding Column.	Additional 250 Gal. per Min. Streams which could be Supplied by Operating All Pumps.
Orange	5 282	1873	161 000	3 000 000	18.6	2 839 000	189.0	4.4
Lincoln	1 175	1874	221 000	1 500 000	6.8	1 279 000	85.3	4.9
Nantucket	2 962	1878	233 000	425 000	1.8	192 000	12.8	6.3
Mansfield	5 183	1883	569 000	242 000	0.4	Empty	None	4.0
Wellesley	5 412	1884	374 000	1 969 000	5.3	1 595 000	106.5	6.7
Franklin	5 641	1884	296 000	423 000	1.4	127 000	8.4	15.3
Sharon	2 310	1885	149 000	188 000	1.3	39 000	2.6	3.8
Kingston	2 445	1886	......	264 000	...	....	....	1.6
Grafton	5 705	1886	114 000	110 000	1.0	Empty	None	4.2
Cohasset	2 585	1886	291 000	1 500 000	5.2	1 209 000	80.6	2.8
Easton	5 139	1887	135 000	242 000	1.8	107 000	7.0	3.9
Tisbury	1 196	1887	......	118 000	...	....	....	2.8
Ayer	2 797	1887	162 000	1 440 000	8.9	438 000	29.3	4.2
Canton	4 797	1889	386 000	468 000	1.2	82 000	5.5	...
Avon	2 013	1890	80 000	212 000	2.7	132 000	8.8	...
Needham	5 026	1890	356 000	314 000	0.9	Empty	None	8.3
Foxborough	3 863	1891	234 000	282 000	1.2	48 000	3.2	4.0
Reading	5 818	1891	234 000	530 000	2.3	296 000	19.7	5.0
Holliston	2 711	1891	69 000	300 000	4.4	231 000	15.4	...
Manchester	2 673	1892	305 000	1 030 000	3.4	725 000	48.3	29.1
Provincetown	4 369	1893	212 000	460 000	2.2	248 000	16.5	5.6
North Brookfield	3 075	1893	......	2 950 000	...	....	....	5.6
Onset	....	1894	71 000	94 000	1.3	23 000	1.5	2.5
Ipswich	5 777	1894	323 000	3 000 000	9.3	2 677 000	178.0	...
Fairhaven	5 122	1894	400 000	500 000	1.3	100 000	6.7	12.6
Rockport	4 211	1895	306 000	317 000	1.0	11 000	0.7	...
Longmeadow	1 084	1895	93 000	80 000	0.9	Empty	None	3.8
Millbury	4 740	1895	190 000	1 500 000	7.9	1 310 000	82.3	4.9

Rutland	1 743	1896	99 000	250 000	2.5	151 000	10.1	3.5
Weston	2 106	1896	106 000	400 000	3.8	294 000	19.6	3.6
Walpole	4 892	1896	538 000	672 000	1.2	134 000	8.9	8.3
Winchendon	5 678	1896	182 000	547 000	3.0	365 000	24.3	7.0
Groton	2 155	1897	98 000	1 174 000	12.0	1 076 000	71.7	...
Billerica	2 789	1898	165 000	433 000	2.6	268 000	17.9	5.3
North Andover	5 529	1898	261 000	1 000 000	3.8	739 000	49.3	8.3
Falmouth	3 144	1899	310 000	755 000	2.4	445 000	29.7	...
Shirley	2 139	1903	64 000	200 000	3.1	136 000	9.1	0.3
Merrimac	2 202	1904	88 000	420 000	4.8	332 000	22.2	6.3
Edgartown	1 191	1906	61 000	200 000	3.3	139 000	9.3	2.3
Oxford	3 361	1906	......	214 000	...	....	....	4.0
Dracut	3 461	1906	53 000	225 000	4.2	172 000	11.5	1.6
North Chelmsford	5 010	1907	70 000	350 000	5.0	280 000	18.6	1.6
Wrentham	1 743	1908	96 000	264 000	2.8	168 000	11.2	2.0
Westford	2 851	1908	71 000	490 000	6.9	419 000	28.0	1.4
Marion	1 460	1908	115 000	235 000	2.0	120 000	8.0	5.6
Bedford	1 231	1909	30 000	235 000	7.8	205 000	13.7	2.0
Brookfield	2 204	....	......	....	...	....	....	...
East Brookfield	....	1909	......	184 000	...	....	....	0.7
Pepperell	2 953	1909	110 000	476 000	4.3	366 000	24.4	2.0
Blandford	717	1909	......	200 000	...	....	....	0.3
Plainville	1 385	1909	37 000	246 000	6.6	213 000	14.2	0.3
Douglass	2 152	1910	......	214 000	...	....	....	1.5
Dudley	4 267	1910	124 000	770 000	6.2	646 000	43.1	2.0
Medway	2 696	1911	......	424 000	...	....	....	2.8
Leicester, Cherry Valley and Rochdale	3 237	1911	......	394 000	...	....	....	1.6
Ashland	1 682	1911	20 000	300 000	15.0	280 000	18.7	1.2
South Hadley, District No. 2,	4 894	1911	......	432 000	...	....	....	2.0
Norton	2 544	1912	104 000	200 000	1.9	96 000	6.4	2.4
Barnstable	4 676	1912	75 000	367 000	4.9	292 000	19.5	2.8
Littleton	1 229	1912	41 000	288 000	7.0	247 000	16.5	1.0
Acton	2 136	1912	......	503 800	...	....	....	2.4
West Groton	....	1912	18 000	212 000	11.7	194 000	12.9	0.3
Mattapoisett	1 233	1913	......	330 500	...	....	....	2.0
West Brookfield	1 327	1913	......	250 000	...	....	....	1.0

WEIGHT OF PIPE.

The portion of the design in which theory plays the smallest part and in which even experience is apt to count for little is the determination of the thickness and weight of cast-iron mains. The static pressure which pipes have to withstand and the breaking strength of the cast iron, are the only elements in determining the proper thickness of the pipes which are even approximately known, and determining the thickness from these elements alone would give pipes of about the thickness of cardboard. For example, a 12-in. pipe, to sustain a pressure of 100 lb. per sq. in., should theoretically have a thickness of shell of one twenty-seventh of an inch. All else in the determination of the thickness is in the nature of guesswork.

The formula used by this Association is —

$$t = \frac{pr}{\frac{1}{5}(16\,500)} + \frac{p'r}{\frac{1}{5}(16\,500)} + 0.25,$$

in which t is the thickness of the shell in inches; r, the radius of the pipe; p, the static pressure in pounds per square inch; p', an assumed water hammer in pounds per square inch; 16 500, the breaking strength of cast iron; and 5, a factor of safety.

Fig. 3 shows the thickness of a 6-in. and a 12-in. pipe for a pres-

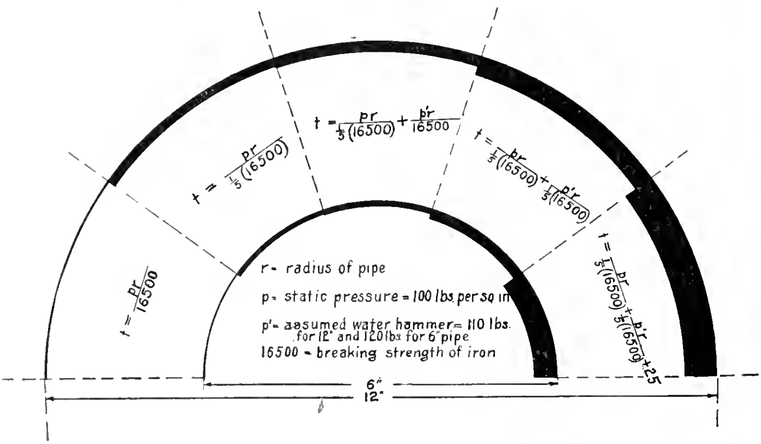


Fig. 3.

sure of 100 lb. per sq. in., built up from this formula. The thickness, using the breaking strength of cast iron and the static pressure, is shown on the left; then with the factor of safety of 5 applied; then with allowance for water hammer of 120 lb. per sq. in. for the 6-in. pipe, and 110 lb. per sq. in. for the 12-in. pipe, using the breaking strength of the iron; then the added thickness for water hammer, applying the same factor of safety; and finally on the right the total thickness of the pipe, adding the 0.25 of an inch for anything which has been left out in the other determinations. It will be seen that the element of guess is the largest element in the determination of the thickness, and that the static pressure has very little relation to the final result. It is also apparent that, if the uncertainties which are provided for in these guesses can be reduced, the thickness can be made much less. The chief uncertainties are the water hammer, the corrosion of the pipe, the possibility of breakage in handling, the strains due to imperfect foundations or unequal settlement, and the eccentricity of the castings and other imperfections in the pipe.

There is no reason why the water hammer in a small town should not be kept well below the figures used in the formula. There are few, if any, authentic cases where corrosion of a cast-iron pipe has caused its failure. In fact, if a pipe has been in the ground long enough to corrode, it seldom fails from any cause. The strains due to imperfect foundations and settlement, in the case of small pipes, can be neglected if proper precautions are taken during construction. The difficulties due to imperfections in the casting and to the handling of thin pipes are the most serious, and to overcome these is the duty of the founders. There is no doubt that they will be overcome if the engineers insist on light pipe, for already much has been done along these lines; the cost per ton may be somewhat increased if lighter pipes are used, but this increased cost will be nothing like the saving accomplished by the use of the lighter pipe.

In my own practice I have put in many miles of Class C pipe where the pressures run up to 115 lb. per sq. in., and have never known of a failure which would have been prevented by using thicker pipe. The breakage in the handling may or may not have been greater. In any case it was not excessive.

For the ordinary conditions in a small town, I would never use a heavier pipe than the Class C, and lighter pipes may safely be used in many cases.

In fourteen of the recently constructed systems in Massachusetts, Class C pipe has been used exclusively; in five places two or more classes have been used in the same town for different pressures. In two towns the A. W. W. Assoc. Class C pipe, corresponding practically to the N. E. W. W. Class F, has been used, and in one town A. W. W. Class B, which corresponds approximately to N. E. W. W. Class D, was used.

DEPTH OF PIPES.

The depths to which street mains should be laid have been investigated by a special committee of this Society,* and the experience of the cold winter of 1911–12 has given valuable if unpleasant experience to those who have had charge of works. The depth determined on affects the cost of the works materially, especially if rock is encountered, and if it is safe to reduce the depth it certainly should be done.

Theoretically, street mains might be laid at different depths in different soils, being a foot nearer the surface in clay than in gravel; but in the average New England town there are so many soils that it is not feasible to make any distinction. The only distinction which it would appear safe to make is in the case of places where the ground water always stands near the surface, where the pipes may be laid in shallow trenches. The freezing of the pipes is such a serious matter that it would seem to be unwise to take any chances in an attempt to save money on trench excavation. The best practice seems to be, for a climate like that of Massachusetts, to have the center of the pipe from 4.75 ft. to 5.00 ft. beneath the surface.

The recent practice in Massachusetts is indicated by the returns from twenty-four towns in which water-works systems have been built in the last ten years. In twelve of the twenty-four towns the pipes are covered to a depth of 4.5 ft. In four towns they were laid in a 5-ft. trench, in three towns the cover was 4 ft., in

* JOURNAL N. E. W. W. A., *23*, 435; *27*, 160.

four towns they were covered 4 ft. 9 in., and in one town the center of the pipe was 5 ft. below the surface of the ground.

The service pipes in 7 of the above towns are laid 5 ft. deep; in 10, 4.5 ft. deep; and in two places they were laid 4 ft. deep.

In small towns where there is no established grade for the streets, changes in the street level are likely to occur; and when these can be foretold, as is possible in some cases, provision should be made for such changes in laying the pipes; but here again it is unwise to go too far into the future, for the expected is liable never to happen, and frequently money spent in anticipation of changes in grade is money wasted.

There are many interesting problems connected with the crossing of streams and the carrying of the pipes over railroads concerning which there is little printed information, and a discussion of which by the members of this Association would bring out many points of great value. Many of the elaborate bridges which have been constructed are undoubtedly needless, and on the other hand there are many cases where pipes carried directly on the highway bridges have given much trouble both by leaking joints and by freezing. These important details cannot be discussed within the limits of this paper.

FINANCIAL PROBLEMS.

Perhaps one of the most serious problems which confronts those interested in the construction of a water-works system in a small town is the problem of convincing the voters that a water-works system will not bankrupt the town. There are always those who believe that a water-works system is not necessary or desirable, that the water obtained from private wells is better than that which has been stored in pipes or reservoirs, and that the notion that well water may be injurious to health is nonsense. Such men are generally not to be convinced by any argument which can be put forward. They are the men who object on principle to improved roads, improved schools, and improvements of any kind. But there are always in every town thinking men who honestly believe that the construction of a water-works system would be such an expensive undertaking that it would be a

TABLE 3.

Town.	Population. (1910.)	Date of Introduction of Works.	Length of Mains. (Miles.)	Cost of Works to Date.	Cost per Mile.	Cost per Inhabitant.
Reading	5 818	1891	32.1	$345 000‡	$10 730‡	$59.30‡
Winchendon	5 678	1896	23.5	184 173	7 850	32.40
Franklin	5 641	1884	18.0	275 000	15 270	48.80
North Andover	5 529	1898	34.0	208 000	6 120	37.60
§Westborough	5 446	1879	16.0	175 000	10 930	32.20
Wellesley	5 412	1884	41.0	416 457	10 150	76.90
Orange	5 282	1873	15.0	200 000	13 330	37.80
Mansfield	5 183	1888	21.3	129 426	6 090	25.00
Easton	5 139	1887	10.0	100 000	10 000	19.45
Needham	5 026	1890	39.3	185 000	4 710	36.80
North Chelmsford	5 010					
Fire District		1907	6.0	80 000	13 330	....
South Hadley	4 894					
District No. 1	....	1872	7.0	120 000	17 150	....
§District No. 2	....	1911	6.0	68 000	11 320	....
Walpole	4 892	1896	22.44	176 871	7 880	36.20
Provincetown	4 369	1893	12.0	125 000	10 400	28.60
Foxborough	3 863	1891	12.1	126 000	10 400	32.60
§Dalton	3 568	1884	5.0	100 000	20 000	28.05
Dracut	3 461	1906	6.9	69 463	10 060	20.10
Leicester	3 237					
§Leicester District	....	1891	8.4	68 658	8 175	....
Cherry Valley and Rochdale	....	1911	15.1	108 245	7 160	....
Falmouth	3 144	1899	43.5	333 643	7 670	106.00
North Brookfield	3 075	1893	9.2	194 828	21 200	63.40
Pepperell	2 953	1909	21.0	124 000	5 900	42.00
Ayer	2 797	1887	12.0	140 516	11 700	50.30
Billerica	2 789	1898	10.4	99 772	9 575	35.80
Medway	2 696	1911	13.0	113 000	8 690	41.90
Manchester	2 673	1892	21.0	447 044	21 250	167.00
Kingston	2 445	1886	12.0	75 000	6 250	30.70
Hopkinton	2 452	1884	8.0	65 000	8 130	26.50
Sharon	2 310	1885	17.3	105 145	6 075	45.50

Deerfield	2 209					
§Deerfield District	....	1911	5.0	31 000	6 200	....
§Wayland	2 206	1878	5.9	45 000	7 630	20.40
Brookfield	2 204					
East Brookfield	....	1909	2.7	28 000	10 320	....
Merrimac	2 202	1904	9.0	86 500	9 610	39.30
Groton	2 155					
†West Groton District	....	1912	3.0	26 000	8 670	....
§Holden	2 147	1905	11.0	74 946	6 810	34.90
*Shirley	2 139	1903	7.0	56 285	8 050	26.30
Acton	2 136	1912	11.5	100 000	8 690	46.90
§Hadley	1 999	1905	8.0	61 004	7 625	30.50
Rutland	1 743	1896	4.5	30 000	6 670	17.20
Wrentham	1 743	1908	11.0	67 500	6 130	38.70
Ashland	1 682	1911	7.5	55 000	7 330	32.70
§Shelburne	1 498	1912	9.7	87 278	9 010	58.20
§Huntington	1 473	1899	5.0	35 000	7 000	23.70
Marion	1 460	1908	14.3	130 500	9 150	89.40
Millis	1 399	1891	10.0	60 000	6 000	42.80
*Plainville	1 385	1909	6.5	45 344	6 980	32.70
†West Brookfield	1 327	1913	6.1	45 000	7 380	33.90
Mattapoisett	1 233	1913	7.0	65 000	9 290	52.70
Bedford	1 231	1909	6.2	66 995	10 800	54.40
†Littleton	1 229	1912	7.0	60 000	8 575	48.75
Lincoln	1 175	1874	25.0	181 000	7 240	154.00
§Erving	1 148	1896	5.6	46 000	8 220	40.10
§Hinsdale	1 116	1889	4.0	37 000	9 250	33.10
Longmeadow	1 084	1895	12.0	50 000	4 170	46.20
§Russell	965	1911	7.0	50 000	7 140	51.80
†Blandford	717	1909	4.8	34 000	7 080	47.50
§Egremont	605	1913	3.5	20 000	5 720	33.10

* Has no pumping plant.
† Has only one pumping unit.
‡ Including filter plant.
§ Gravity systems.

TABLE 4.

Cost of Pumping Stations, Pumping Machinery, and Distributing Reservoirs in Recently Constructed Water-Works Systems.

Town.	Population. (1910.)	Pumping Station.			
		Material.	Size.	Cost.	Cost per Sq. Ft.
Ashland	1 682	Cobbles	22 x 30	$1 935	$2.93
Bedford	1 231	Brick	19 x 36	1 857	2.71
Deerfield	....	Cobbles	9 x 12	350	3.24
Dracut	3 461	Wood and steel shingles over entire surface.	.....	1 730	...
Dudley	4 267	Brick	24 x 26	1 948	3.12
East Brookfield	....	Brick	24 x 30	1 628	2.26
East Douglass	2 152	Brick	20 x 35†	2 500	3.57
Leicester (Cherry Valley and Rochdale)	...	Brick	30 x 40	2 368	1.97
Littleton	1 229	Brick	24 x 34	3 100‡	3.80‡
Marion	1 460	Brick	.....	...	...
North Chelmsford	5 010	Brick	33 x 23	2 000	2.64
Oxford	3 361	Brick	24 x 24	2 000	3.46
Pepperell	2 953	Brick	28 x 38	2 852	2.68
So. Hadley (Fire Dist. No. 2.)	....	Brick	25 x 36	2 700	3.00
Wareham	....	Brick	25 x 36	2 133‖	2.37‖
West Groton	....	Brick	16 x 16	500‖	1.95‖
Wrentham	1 743	Brick	25 x 36	1 647‖	1.83‖

Town.	Pumping Machinery.			
	Pumps.	Engines.	Cost.	Cost per Horse-Power.
Ashland	2–7 x 8	2–18 h.p. Oil	$4 358	$121.00
Bedford	2–8½ x 10	2–25 h.p. Gasoline	4 000	80.00
Deerfield	1–4 x 6	1–7½ h.p. Motor	475	63.30
Dracut	1–8 x 10	1–20 h.p. Gasoline	1 783	89.15
Dudley	2–8 x 10	2–25 h.p. Motors	2 500	50.00
East Brookfield	2–5½ x 8	2– 8 h.p. Oil	3 100	193.75
East Douglass	1–10 x 10 1–7¼ x 10	1–35 h.p. Motor 1–15 h.p. Motor	2 455	49.10
Leicester (Cherry Valley and Rochdale)	2– 8 x 10	2–18 h.p. Oil	4 414	122.50
Littleton	1–7½ x 10	1–25 h.p. Oil	3 960	158.50
Marion	2–7½ x 8*	2–40 h.p. Oil	8 157	102.00
North Chelmsford	2–7¼ x 10	2–25 h.p. Motors	3 500	70.00
Pepperell	2– 8 x 10	2–25 h.p. Oil	6 200	124.00
South Hadley (Fire Dist. No. 2)	2– 8 x 10	2–35 h.p. Oil	6 875	98.25
Wareham	2– 8 x 10	2–25 h.p. Oil	5 642	112.80
West Groton	1– 6 x 8	1–10 h.p. Gasoline	1 163	116.30
Wrentham	1– 8 x 10	1–25 h.p. Oil	2 821	112.80
Wrentham State School	2– 6 x 8	2–10 h.p. Motors	1 784	89.20

* Double acting.

† Two stories.

‡ Includes some grading.

‖ Without pumping machinery foundations.

TABLE 4.—*Continued.*

Town.	Distributing Reservoir.					
	Kind.	Size, Diameter, Height.	Capacity (Gals.)	Cost of Foundation.	Cost, including Foundations.	Cost per 1 000 Gallons.
Ashland	Concrete Standpipe	40 x 32	300 000	...	$5 812	$19.35
Bedford	Steel Standpipe	20 x 100	235 000	$1 030	6 610	28.25
Dracut	Reservoir	.....	225 000	....	2 385	10.60
Dudley	Reservoir	71 x 26	770 000	....	20 232	26.20
East Brookfield	Steel Standpipe	25 x 50	184 000	300	3 550	19.30
East Douglass	Concrete Standpipe	45 x 18	214 000	....	4 521	21.15
Leicester (Cherry Valley and Rochdale)	Concrete Standpipe	40 x 21	197 000	....	4 976	25.25
Littleton	Steel Standpipe	35 x 40	288 000	700	4 638	16.10
Marion	Steel Standpipe	20 x 100	235 000	....	5 883§	25.00§
North Chelmsford	Steel Standpipe	22 x 125	355 000	....	9 772	27.50
Oxford	Steel Standpipe	27 x 50	214 000	400	5 060	23.60
Pepperell	Steel Standpipe	45 x 40	476 000	839	6 707	14.10
Plainville	Steel Standpipe	25 x 67	246 000	710	4 979	20.25
So. Hadley (Fire Dist. No. 2)	Steel Standpipe	35 x 60	432 000	....	6 165§	14.30§
Wareham	Steel Standpipe	20 x 100	235 000	....	6 835§	29.10§
West Groton	Steel Standpipe	30 x 40	212 000	613	4 021	18.95
Wrentham	Steel Standpipe	30 x 50	264 000	800	6 000	22.70
Wrentham State School	Steel Standpipe	22 x 50	142 000	368	2 596	18.25

§ Without foundation.

NOTE.—All pumps are vertical, single-acting, triplex pumps, unless otherwise noted.

great mistake for the town to enter into it. The best solution of this problem—the problem of convincing the honest doubters—is to use the experience gained by other towns of similar size which have already put in works. With this in view, I have collected certain information from the small towns in Massachusetts which have been supplied with water, and tabulated the returns. The great difficulty in getting together this information is the lack of proper systems of accounts. In most cases it is impossible to obtain information of any value from the printed reports, and in many cases it cannot be obtained even from a study of the books. The officials themselves cannot dig out the information. Construction accounts and maintenance accounts are hopelessly mixed, and the vouchers in many cases do not show for what the money has actually been spent.

Perhaps it is only fair to say here that the salaries of superintendents in small towns are from fifty dollars per year up—and some of them do not go very far up, either. As the superintendent is generally, to use the language of one of them, "registrar, clerk of board, draftsman, engineer, etc.," it is not strange that the sys-

tem of accounts is not very elaborate. The average salary of the superintendents in towns having steam pumping systems is $1 080. The average salary of those where pumping is done by oil engines or electric motors is $818. Of the latter group practically all operate the pumps themselves.

Table 3 gives the best figures which I have been able to obtain as to the total cost to date of many of the small water-works systems in Massachusetts. Here I have found instances where the total cost of the works carried on the books has included the amount paid for maintenance each year. Such of these cases as have been found have been corrected, but there may be some which have not been discovered. Naturally the difference in local conditions makes a difference in the cost, but the table, with a general knowledge of the towns, contains some very valuable information.

Table 4 is also presented showing the cost of pumping stations, pumping plants, and distributing reservoirs.

For obvious reasons the plants which are owned by private companies are not included in the table, but in general it may be said that the cost, both of construction and of maintenance, of privately owned plants is fully as great as that of the plants owned by the towns.

DISCUSSION.

Mr. Edward V. French.* As Mr. Johnson read his paper those of us who are always looking at the fire side were, I think, somewhat fearful at some of the limitations he was proposing; but as he went on he made it very clear that he was talking about the really small towns. As he developed the subject we saw that he was making a plea all the way through for the distribution of the money that is available over the whole system, so that every part of the town would get that protection which it needed from a fire standpoint and would not get less than it needed because some other part of the town got more. In other words, he was making a plea for the distribution of the service in proportion to the needs of the different sections. So, taking it all in all, although

* Vice-President and Engineer, Arkwright Mutual Insurance Company, Boston, Mass.

some of the figures seem small, I am inclined to think that it is really a very reasonable limitation which he places upon the amount of fire protection, such, for instance, as that to be provided for the sparsely built-up sections. Following the lines which he has suggested, a small town would get a fire system which would give it reasonably good fire protection in every part, and, as Mr. Johnson has stated, if you get that, there will always be sufficient water for other purposes.

Mr. Johnson's remarks about 4-in. pipe were somewhat heretical, as we have looked at it, but, perhaps with some modification, they may nevertheless be reasonable. He has in mind a district that is very little built up. If we take a street which has no hydrant on it, the chief use of the pipe through it is to carry water for domestic purposes, and in that case there may be a place, in spite of all we have said in the past, for a 4-in. pipe. I suppose Mr. Johnson would modify his suggestion to this extent: that if the various cross-feeders, which we might think he means to make 4 in., are part of a gridiron system, and consequently necessary to bring into any section a liberal amount of water, then the 4-in. pipe becomes too small. That is, it may be all right as a single local feeder, but we must not get away very far from the good old rule that 4-in. pipe should be treated gingerly, and used, when used at all, with a great deal of good judgment.

Mr. Johnson mentioned the mill fire pump. Those of us who are interested in the protection of mill properties would always be very glad to advise our people to allow the use of their fire apparatus for the good of the town. We have always done so in the past, and before pollution was a danger this used to be done a good deal. In later days many of those connections have had to be cut off or safeguarded in some way. While the mill people are more than willing to help, the conditions from the standpoint of health are such that this use of the mill fire pump can be made only when the water it discharges will be unpolluted, or possibly in the rare case where a little chance might be taken because the danger might be less than that which a sweeping fire would cause to health and even life.

Mr. S. H. MacKenzie.* Mr. Johnson said he thought 150 lb.

* Superintendent Water-works, Southington, Conn.

pressure was not objectionable in a water system. We noticed last year, when feeding from a high-service reservoir, that our meter readings were uniformly increased, which shows that leaky fixtures will waste more water and that good fixtures will become worn much quicker under the greater head. It seems to me that for domestic service from 80 to 100 lb. would be preferable to 150 lb. It would of course be advisable to have the mains of such size as to maintain the pressure as near uniform as possible.

Mr. Johnson. I might say in answer to that, that I limited it to new systems. It seems to me it makes all the difference in the world whether it is a new system of water works or an old system. In a new system, where the plumbing is new and can be made to resist the pressure, I think it is much better to get up to 150 lb. than it is to try to maintain two different pressures in the same town.

Mr. R. D. Chase. When the city of Springfield was considering the Little River supply, this subject was studied quite carefully, with the result that the whole city was put on one service, bringing the previous low-pressure service up to from 135 to 145 lb. I think there has been no serious trouble, and I believe no one now regrets the change to the higher pressure. Quite a number of towns were visited in course of the studies where pressures as high as 150 lb. were in use without serious objection.

In regard to one point which Mr. Johnson made about the isolated stations: I recall that in Westfield, Mass., there is a small water-driven electric-light plant supplying a hotel about a mile distant. A private telephone line connects the station with the hotel office. At the station the receiver is always off the hook, so that at any time from the hotel one can listen to the operation of the plant. I see no reason why this could not be done at the very small pumping station.

Mr. A. R. Hathaway.* The lower level, or down-town portion, of Springfield was formerly supplied by the old low-service system which gave a maximum pressure of about 35 lb. The larger number of old tenement premises were located in this section. At that time the high-service supply from Ludlow gave a maximum pressure of about 135 lb. in this lower portion, but was

* Water Registrar, Springfield, Mass.

not used for these tenements because of the old and weak plumbing.

When the supplies were both superseded by the new supply from Little River, with a maximum pressure of about 145 lb. in the down-town section, it became necessary to replace the service pipes for this class of property with new and stronger pipes from the street main to the building. The cost of these services was equitably divided between the property owner and the water department. Pressure regulators were also installed between the new services and the old plumbing, the consumer paying only the actual cost of same to the department. In this manner we overcame the objection spoken of, and the consumers having become accustomed to the new situation, we now have very little trouble.

Mr. Frank L. Fuller.* When the Wellesley works were built in 1884 we had occasion to cross the railroad on an overhead bridge. The pipe, which was put in a box filled with tanbark, froze the first winter. Since then, when we have had other occasions to cross the same railroad, we have used two boxes with an air space between, and have had no trouble.

In the town of Ware, in 1886, we had occasion to cross a stone arch bridge, where there was a covering of only about a foot of earth over the arch stones. We placed a drinking fountain so that there was a continuous flow in the pipe over the arch, and there never was any trouble from freezing.

At Franklin, N. H., we had to cross the river on an old toll bridge, which had considerable span and so little stiffness that when teams were passing there was a good deal of vibration. The pipes were strapped together with long rods and gave no trouble.

In regard to the weight of pipe, I think there has been a great deal of iron pipe laid which was unnecessarily heavy. I have generally recommended for 6-in. pipe, 30 lb. to the foot; for 8-in., somewhere in the neighborhood of 43 or 44 lb.; for 10-in., 60 lb., and for 12-in., 75 lb. This may seem light and less than some of our standards, but if you will reckon up and see what the difference of a few pounds per foot will amount to in eight or ten miles, you will find it is quite a large sum of money. I believe that if the

* Civil Engineer, Boston, Mass.

pipe is heavy enough to stand railroad transportation and the teaming from the freight station to the place where it is laid, there will be no trouble on account of pressure. I believe that the corrosion of the pipe will not be sufficient to affect its strength during the length of time it will be in the ground.

MR. HENRY A. SYMONDS. When we come to make improvements, or repairs, or extensions, I think in probably one out of every half dozen plants in the state that were built more than fifteen years ago we find that the sizes of pipes are very much out of proportion to the particular service which they were supposed to render. That was in many cases, perhaps, due to the inability of the builders of the works to size up the requirements that the plant would be subjected to. But in many cases it was due to lack of knowledge of what these systems were able to accomplish.

That brings to my mind a case where I was called in a few years ago, which perhaps illustrates how some or at least how one of our water commissions design and build water works. A certain town in the central part of the state laid out a small piping system. They submitted the matter to me a little later, for although it was supposed to be a gravity supply, they could not get the water into the town and they could not exactly see why, for the plan showing the lay-out of the pipes gave the elevation of the reservoir as considerably above the town. On a little investigation it developed that, while there was a valley coming down to the town, it was somewhat roundabout, so the water commissioners, not thinking it necessary to get any expert advice, decided that the correct thing to do in this case was to put in a siphon; and so they had piped straight over a hill to the town and had gone to an elevation of about 100 ft. above the reservoir.

The placing of hydrants is always a matter which, it seems to me, is worked out on an entirely wrong principle, and how to remedy it is considerable of a problem. The rate is ordinarily made in accordance with the number of hydrants. Mr. Johnson has pointed out to us very clearly how the expense of increasing the number of hydrants amounts to but little compared with the expense of the whole plant. Here is a plant, perhaps, which may cost $75 000, and an expenditure of $40 apiece additional, we will say, for twenty or thirty hydrants, may make all the difference

between a plant which is first class from the insurance point of view and one which is entirely inadequate to take care of the service. But the town is starting out in the face of so much per hydrant, which has got to be paid year after year, and the result is that in four cases out of five the hydrants are cut down to about two thirds of what the number should be.

I wish also to express my approval of the idea that Mr. Johnson has spoken of in regard to 4-in. pipe. There are many places where a 4-in. pipe is entirely sufficient; for instance, on short cross streets. It has a very much greater length of life than wrought-iron small pipes, and the expense of installing it is comparatively small.

In regard to breakage of pipe, a case came to my attention on a pumping plant where, after the pump was installed, they began to have breaks. The pipes were not very heavy, but they seemed to be as heavy as the service required, and at first we were entirely at a loss to know what the trouble was. Finally on an examination of one of the pumps it was found that there was something defective with the packing, so that they were pumping air into the pipe. The result showed that this was the cause of the breakage, because immediately upon repacking the pump the breaking stopped.

Mr. Raymond W. Parlin.* There were one or two points in Mr. Johnson's paper which I would like to corroborate from the experience of the American Water Works and Guarantee Company. One of them is that in some thirty plants which they control they have made a practice of using Class A of the American Water Works specifications, which is practically the same as Class C of the New England Water Works Association specifications. They have used this pipe up to 125 lb. pressure and have had no trouble with it.

One of the main troubles with private water company operation, and also with municipal plant operation, comes from a lack of education of the public. The water-works officials often do not realize that the ordinary citizen wants to know a little something about the plant which is supplying him with water, and as the result of their ignorance the people often get misconceptions

* Resident Engineer, Washington County Water Company, Maryland.

which cause trouble. One case, for instance, is the use of a filtered supply as an emergency source. One city of about 22 000 population had an emergency source which was perfectly good if filtered, the use of which saved some $15 000 a year. The people, not knowing why that source was used, not knowing that the saving would mean a less rate to them, always put up a great complaint every time the company started to use it. They would say, "You ought to have provided for this in the first place." The fact is, if the company had provided for it in the first place, a lot of unnecessary capital would have been required, and it would have been necessary to have increased the rates in order to make proper earnings.

In the matter of fire protection, very often the efficiency of a plant is not dependent on the design or on the operation, but it is dependent on the fire department, which is altogether outside the control of either the engineer or the water-works officials. I have seen the fire department connect up with two lines of hose from a hydrant 600 or 700 ft. away, and leave a hydrant within 150 ft. of the fire unused. I have seen them connect up an engine to a hydrant within 200 ft. of the fire, and run an ordinary hose line from a hydrant 500 or 600 ft. away, and of course the engine spoiled the streams from the hydrant. Now, if you have that sort of service in your fire department, they are going to spoil even a good water system, or if the water system is just right they will defeat its purpose. In the case I speak of, the water system was just on the edge. If it was carefully handled at fires they had plenty of water for practically every portion of the city, but under the careless way in which it was handled they got very poor protection. Yet in that particular city, as the result of one examination by the insurance companies, they practically omitted the fire department from their criticism, when really it was responsible for most of the trouble.

I think Mr. Johnson's criticism as to pressure is illustrated very well in a town in Maryland where the original system was designed for a pressure of 55 lb., with the idea of using fire engines for bad fires. Subsequently the pressure was increased, causing leaks all over the town which were due entirely to the plumbing having been installed under the old pressure. An unfortunate thing in

that case was that one of the first leaks occurred in the house of the mayor, and it started trouble right off. That was a case of a privately owned company.

MR. FRENCH. Even in a rather small town there is sometimes a fairly well built-up section; the houses may not all be very near together, but they are all in a certain area. Now, although a single house in a small area, well separated, may be protected by the small quantities of water Mr. Johnson mentions, it is very easy for a small town to have a fire which will spread into various sections. I remember when the village of Fryeburg in Maine burned, I reached there soon after the fire started, and found, when I came into the town, two or three houses perhaps a quarter of a mile back from the scene of the main fire burning, having been ignited by sparks. Under those conditions the small water-works system may be called upon to supply water at several points simultaneously. This feature must not be forgotten, and is another reason why we must be very careful about using 4-in. pipe.

PROPOSED
STANDARD SPECIFICATIONS FOR POST HYDRANTS.

[*Adopted* at the special meeting, April 15, 1914.*]

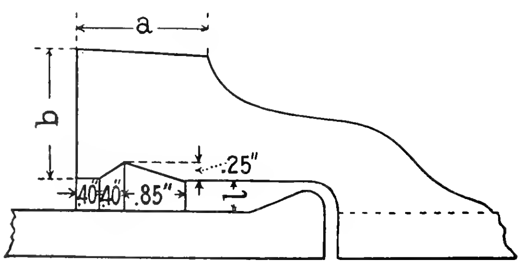
Final Report of the Committee.

1. Size.

a. The size of hydrants shall be designated by the nominal diameter of the valve opening, which must be at least 4 inches for hydrants having two $2\frac{1}{2}$-in. hose nozzles; 5 inches for hydrants having three $2\frac{1}{2}$-in. hose nozzles; and 6 inches for hydrants having four $2\frac{1}{2}$-in. hose nozzles, and shall be classed as one-way, two-way, three-way, or four-way, according to the number of $2\frac{1}{2}$-in. hose outlets for which they are designed.

b. The net area of the waterway at the smallest part other than at the valve opening when the hydrant is wide open must not be less than 120 per cent. that of the valve opening, and there must be sufficient clear waterway through the hydrant when wide open to allow the passage of a ball at least *$1\frac{7}{8}$** in. in diameter for a two-way and *$2\frac{3}{8}$** in. for three- and four-way hydrants.

In new designs it is recommended that inside diameter of hydrants, especially at the outlets, be 7 in. for two-way and 8 in. for three- and four-way hydrants.



c. Hydrants must be fitted with bell ends to fit standard cast-

* The parts of this report printed in italics have been referred back to the committee for farther consideration or revision.

TABLE 1.

Nominal Diam. Inches.	Classes.	Actual Outside Diameter. Inches.	Pipe Sockets.		"a."	"b."
			Diameter. Inches.	Depth. Inches.		
6	All	7.10	7.90	3.00	1.50	1.40
8	All	9.30	10.10	3.50	1.50	1.50

iron pipe, the dimensions of which are given in Table 1, or with flanges of standard dimensions and having standard bolt layouts, as given in Table 2. Holes are not to be drilled on the center line, but symmetrically each side of it.

TABLE 2.

Size of Pipe. Inches.	Diameter of Flange. Inches.	Flange Thickness at Edge. Inches.	Diameter of Bolt Circle. Inches.	Number of Bolts.	Size of Bolts. Inches.
6	11	1	$9\frac{1}{2}$	8	$\frac{3}{4}$ x 3
8	$13\frac{1}{2}$	$1\frac{1}{8}$	$11\frac{3}{4}$	8	$\frac{3}{4}$ x $3\frac{1}{2}$

Where working pressure is from 150 to 250 lb., the standard for heavy flanges must be used.

2. General Design.

a. Hydrant may be of compression or gate type.

b. Hydrants must be designed to safely withstand a working pressure of 150 lb., with a factor of safety of at least 5 at the working pressure. For example, a hydrant whose working pressure is 150 lb. must resist a pressure of 750 lb. before breaking.

c. Valve when shut must remain reasonably tight when upper portion of barrel is broken off.

There is some danger of the hydrant being broken off, and in such cases it is desirable to have the hydrant gate remain reasonably tight.

d. Any changes in diameter of the water passage through the hydrant must have easy curves, and all outlets must have rounded corners of good radius.

e. * *With the hydrant discharging 250 gal. per minute through each 2½-in. hose outlet, the total friction loss of the hydrant must not exceed 1¾ lb. for two-way, 2¼ lb. for three-way, and 3 lb. for four-way hydrants, except when fitted with inside hose gate valves, in which cases the loss must not exceed 2¾ lb. for three-way and 3½ lb. for four-way hydrants.*

f. Hydrants must be so designed that with extraordinary usage they will not cause an increase of pressure in the system above normal of more than 60 lb.

g. Hydrants must be fitted with two lugs so that the leaded joint underground can be strapped.

h. When hydrant barrel is made in two sections, the upper flange connection must be at least 2 in. above the ground line.

In clayey soils where the ground packs closely about the hydrant and tends to grip it, freezing and consequent heaving of the ground would bring some strain on the hydrant, especially if there were flanges near the ground level. To overcome this effect the flanges should be put above ground and the hydrant surrounded from bottom to ground level with a 3-in. layer of gravel. About ½ bu. of small stones should be placed around the base of every hydrant to serve as a drain, unless the drip from hydrant is connected to some waste pipe.

3. Material of Body.

a. The hydrant body must be made of cast iron.

4. Materials.

a. The metal for all iron castings must be of good quality, and of such character as shall make the metal strong, tough, and of even grain, and soft enough to satisfactorily admit of drilling and machining. The metal must be made without any admixture of cinder iron or other inferior metal, and must be remelted in a cupola or air furnace. The castings must be smooth, free from scales, lumps, blisters, sand holes, and defects of every nature which unfit them for the use for which they are intended. No plugging or filling will be allowed.

Specimen bars of the metal used, each being 26 in. long by 2 in. wide and 1 in. thick, must be made without charge as often as the

* The parts of this report printed in italics have been referred back to the committee for further consideration or revision.

engineer may direct, and in default of definite instructions, the manufacturer must make and test at least one bar from each heat or run of metal. The bars when placed flatwise upon supports 24 in. apart, and loaded in the center, must support a load of 1 900 lb., and show a deflection of not less than .30 in. before breaking; or if preferred, tensile bars may be made which must show a breaking point of not less than 21 000 lb. per sq. in., bars to be cast as nearly as possible to the dimensions without finishing, but corrections may be made by the engineer for variations in width and thickness, and the corrected result must conform to the requirements.

b. All wrought iron or mild steel used must be of the best quality of double refined iron, of a tensile strength of at least 50 000 lb. per sq. in.*

c. All composition or other non-corrodible metal used must be of the best quality, to have a tensile strength of not less than 30 000 lb. per sq. in., with 5 per cent. elongation in eight diameters and 5 per cent. reduction of area at breaking point. Composition for inside hose valve stems must have a tensile strength of not less than 55 000 lb. per sq. in. and an elastic limit of not less than one half the tensile strength.

5. *Hose Valves and Nipples.*

a. Hydrants must have at least two hose connections.

b. If hose gate valves are used they must be of the outside detachable type or be built inside the barrel. The outside hose gate valves must be made of composition or of iron with composition trimmings, with lugs cast on the valve body, and each valve must be bolted to the hydrant by two $\frac{3}{4}$-in. tap bolts, spaced horizontally $5\frac{5}{8}$ in. on centers. The valves must not project further than necessary, and must be of the inside screw type, placed in a vertical position, with the hand-wheel at least 3 in. below the base of the operating nut.

Inside hose-gate valves must have composition metal working parts and be of rugged design, and must not introduce an unnecessary friction loss. There must be ample clearance between

* The parts of this report printed in italics have been referred back to the committee for further consideration or revision.

the gate and the hydrant body when the gate is in any position. The gate and parts should be interchangeable, and the valves should be located so as to be as accessible as possible for repairs. The gate must be designed so that it cannot come off in use. The top of the stem must be below the level of the hydrant stem nut, so that the hydrant wrench can be freely operated.

c. Hose nipples must be of composition metal threaded with a fine thread into the hydrant, and securely pinned or carefully locked and calked in place. If desired, the nipple may be cast with two side lugs and be bolted to the hydrant.

d. Hose threads on all hydrants to be installed in any given district must of necessity be interchangeable with those already in service, but, where practicable, threads should conform to the National Standard. The essential features of the "National Standard" thread in the $2\frac{1}{2}$ in. size are a 60 degree V-thread, outside diameter on male threads of $3\frac{1}{16}$ in. and $7\frac{1}{2}$ threads per inch.

e. The stems of the hose valves must be not less than $\frac{3}{4}$ in. in diameter for the $2\frac{1}{2}$-in. valves, and not less than $\frac{7}{8}$ in. in diameter for the valves at the steamer connections.

f. The stem nut of all inside hose and steamer connection gate valves must be $\frac{1}{2}$ in. square.

6. Hydrant Valve.

a. The valve seat must be made of composition metal securely threaded in place.

b. The valve must be faced with a yielding material, such as rubber or leather, except that if of the gate type, a bronze ring may be used. The valve must be designed so that it can be easily removed for repairs without digging up the hydrant.

c. The clearance of parts must be such that corrosion will not make the parts inoperative.

7. Drip Valve.

a. A positively operating non-corrodible drip valve must be provided and arranged so as to drain the hydrant when the main valve is shut.

b. The seat of the drip valve must be made of non-corrodible

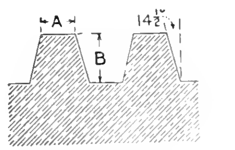
metal and must be securely fastened in the hydrant. All other parts of the drip mechanism must be designed to be easily removed without digging up the hydrant.

8. Operating Stem.

a. The threaded section of the operating stem when located in the waterway must be of composition or other non-corrodible metal, but when above the stuffing box it may be of wrought iron, or mild steel.* The operating stem, where it passes through the stuffing box and gland, must be of composition metal or be fitted with a composition metal covering. The diameter of the operating stem at base of thread must not be less than $1\frac{1}{8}$ in. for gate type of hydrant and 1 in. for compression and toggle types. The remainder of stem may be of iron and the diameter must not be less than $1\frac{3}{8}$ in. for gate type of hydrant and $1\frac{1}{4}$ in. for compression and toggle types. The operating stem must be attached, so that in operation it will be impossible for it to become detached.

b. The stem must terminate at the top in a nut of pentagonal shape, finished with slight taper to $1\frac{1}{2}$ in. from point to flat, except for hydrants to be installed where existing hydrants have different shape or size of nut, in which case the additional hydrant must have the same operating nut as the old ones for uniformity. The nut socket in the wrench must be made without taper so as to be reversible.

c. The thread which operates the valve must be Acme, half V or square. The Acme standard thread is shown in Fig. 1.



$$A = \frac{0.3707}{\text{No of threads per inch}}$$

$$B = \frac{1}{\text{Twice No of thds per inch}} + .01''$$

FIG. 1.

9. Stuffing Box and Gland.

a. The stuffing box and gland must be of composition metal or bushed with it. If a packing nut is used, it must be of composition metal. The bottom of the box and end of the gland or packing nut must be slightly beveled.

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*The iron threaded section is permissible only where the hydrants are to receive the best of care and be kept oiled, otherwise composition must be used to insure reliable operation.

b. Gland bolts or studs must be of composition metal, wrought iron, or steel, at least $\frac{1}{2}$ in. in diameter. The nuts must always be of composition metal.

10. Hydrant Top.

a. The hydrant top must be designed so as to make the hydrant as weatherproof as possible, and thus overcome the danger of water getting in and freezing around the stem. Provision must be made for oiling both for lubrication and to prevent corrosion. A reasonably tight fit should be made around stems.

b. There must be cast on the hydrant top, in characters raised $\frac{1}{8}$ in., an arrow at least $2\frac{1}{2}$ in. long, showing direction to open, and the word " OPEN " in letters $\frac{3}{4}$ in. high.

11. Hose Caps.

a. Hose caps must be provided for all hose outlets, and must be securely chained to the barrel with a welded chain of wire, not less than $\frac{1}{8}$ in. in diameter.

b. The hose cap nut must be of the same size and shape as the operating nut.

c. A leather or rubber washer must be provided in the hose cap, set in a groove to prevent its falling out when the cap is removed. If desired, a lead washer or disk may be used, so retained in the cap that it will not fall out.

12. Marking.

a. Hydrants must be marked with the name or trademark of the manufacturer and the year of manufacture. All letters and figures must be cast on the hydrant well above the ground line. They must be 1 in. high and raised $\frac{1}{8}$ in. on the casting except the date mark, which may be abbreviated, and may be smaller if legible.

13. Testing.

a. Hydrants, after being assembled, must be tested to at least 300 lb. per sq. in. before leaving the factory. If the working pressure is over 150 lb. per sq. in. the hydrants must be

tested to twice the working pressure. The test should be made with the valve open in order to test the whole barrel for porosity and strength of hydrant body. A second test should be made with the valve shut in order to test the strength and tightness of the valve.

b. Hydrants must be fully opened and closed before shipping in order to test the freedom and strength of the parts. The conditions of the test should be made as severe as are liable to occur in service when using a hydrant wrench at least 17 in. long.

14. Direction to Open.

a. All hydrants must open to the left (counter-clockwise), except where existing hydrants open to the right, in which case additional hydrants should turn the same as the old ones for the sake of uniformity.

H. O. LACOUNT, *Chairman*,
GEORGE A. STACY,
FRANK A. MCINNES,
FRED W. GOW,
WILLIAM F. SULLIVAN,
Committee.

PROCEEDINGS.

Special Meeting.

Hotel Brunswick,
Boston, Mass., April 15, 1914.

President Frank A. McInnes in the chair.

The following members and guests were present:

Members.

A. F. Ballou, L. M. Bancroft, G. W. Batchelder, A. E. Blackmer, E. M. Blake, C. A. Bogardus, George Bowers, E. C. Brooks, C. A. Carpenter, R. D. Chase, J. C. Chase, R. C. P. Coggeshall, W. R. Conard, A. W. Cuddeback, J. C. DeMellow, Jr., J. M. Diven, E. D. Eldredge, Patrick Gear, F. J. Gifford, A. S. Glover, Clarence Goldsmith, F. W. Gow, R. A. Hale, R. K. Hale, F. E. Hall, T. G. Hazard, Jr., A. R. Hathaway, D. A. Heffernan, D. J. Higgins, A. C. Howes, F. T. Kemble, E. W. Kent, Willard Kent, Patrick Kieran, A. C. King, G. A. King, H. O. Lacount, E. E. Lochridge, F. A. McInnes, James A. McMurry, A. E. Martin, John Mayo, F. E. Merrill, H. A. Miller, William Naylor, Henry Newhall, F. L. Northrop, R. W. Parlin, T. A. Peirce, J. A. Rourke, J. E. Sheldon, G. H. Snell, G. A. Stacy, T. V. Sullivan, W. F. Sullivan, H. L. Thomas, R. J. Thomas, E. J. Titcomb, G. W. Travis, C. H. Tuttle, J. C. Whitney, G. E. Winslow, I. S. Wood, F. H. Carter. — 64.

Associates.

Builders Iron Foundry, by A. B. Coulters; Chapman Valve Manufacturing Company, by V. N. Bengle, Robert Shirley, A. C. Pilcher, C. E. Pratt, and J. F. Mulgrew; Darling Pump and Manufacturing Company (Ltd.), by J. L. Hough and H. A. Snyder; Eddy Valve Company, by John Knickerbocker; Hersey Manufacturing Company, by Albert S. Glover and W. A. Hersey; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor, J. H. Caldwell, and G. A. Miller; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin; National Water Main Cleaning Company, by B. B. Hodgman; Norwood Engineering Company, by H. W. Hosford; The Pitometer Company, by E. D. Case; Pittsburgh Meter Company, by J. W. Turner; Pratt & Cady Company, by W. D. Cashin and E. L. King; Rensselaer Valve Company, by R. J. Rasmason; Ross Valve Manufacturing Company, by William Ross;

The Leadite Company, by C. A. Vance; A. P. Smith Manufacturing Company, by D. E. O'Brien and F. L. Northrop; Thomson Meter Company, by E. M. Shedd; Water Works Equipment Company, by W. H. VanWinkle; R. D. Wood & Co., by C. R. Wood and H. N. Simons; Henry R. Worthington, by Samuel Harrison; C. H. Millar & Son, by C. F. Glavin. — 34.

GUESTS.

R. C. Harlow, water commissioner, Plymouth, Mass.; W. O. Teague, D. Maynard Sullivan, Boston, Mass.; F. S. Loverrell, Providence, R. I.; H. F. Conant, superintendent water works, Attleboro, Mass.; E. F. Hughes, chairman water board, Watertown, Mass.; H. L. Sherman, Boston, Mass., and George Fred Whitney, Natick, Mass. — 8.

The Secretary presented applications for active membership, properly endorsed and recommended by the Executive Committee, from the following-named persons:

Wallace Willett, East Orange, N. J., consulting engineer, New York City; Fred L. Cushing, Medford, Mass., water registrar; Charles H. Smith, West Medford, Mass., engineer Associated Factory Mutual Fire Insurance Company; Walter H. Merchant, Jr., New Bedford, Mass., engineer both steam and water types of fire apparatus; Henry T. Gidley, Fairhaven, Mass., superintendent Fairhaven Water Company; Charles H. Mitchell, Toronto, Canada, consulting hydraulic engineer; Louis K. Rourke, Boston, Mass., general engineering; A. N. Beer, Ottawa, Ontario, engineer; Edward C. Sherman, Brookline, Mass., engineer engaged in private consulting practice; Fred A. Darling, Franklin, Mass., superintendent and chief engineer, Franklin Water Department; Herbert L. Sherman, Belmont, Mass., chemist and cement expert, president New England Bureau of Tests, Inc.; F. L. Fellowes, Vancouver, B. C., city and water works engineer, Vancouver.

On motion of Mr. Edwin C. Brooks, the Secretary was instructed to cast one ballot in favor of the applicants, and he having done so, they were declared duly elected members of the Association.

Mr. Clarence Goldsmith, assistant engineer, read a paper entitled "A Study of Cast-Iron Bell and Spigot Water Pipe Joints by the Public Works Department, City of Boston."

President McInnes then called Mr. George A. King to the chair, and the meeting proceeded to a discussion of the report of the Committee to Prepare a Standard Specification for Fire Hydrants.

The report was submitted in print, and the discussion was opened by Mr. H. O. Lacount, chairman of the committee. Other gentlemen who took part in the discussion were Mr. F. A. McInnes, Mr. Clarence Goldsmith, Mr. Elbert E. Lochridge, Mr. Frank L. Fuller, Mr. D. F. O'Brien, of the A. P. Smith Manufacturing Company; Mr. George A. Stacy; Mr. John Knickerbocker, president of the Eddy Valve Company; Mr. C. R. Wood, Mr. R. D. Chase, Mr. Walter O. Teague, Mr. Patrick Gear, Mr. Caldwell, and Mr. James M. Diven.

The principal discussion was in regard to the standard size of hydrants under Section 1*a*, which, as submitted by the committee, read as follows:

"Hydrants must be designated by the number of $2\frac{1}{2}$-in. hose outlets for which they are designed, the diameter of the valve opening being at least 5 in. for two-way and 6 in. for three- and four-way hydrants."

For this, by a vote of 30 to 13, on motion of Mr. J. M. Diven, was substituted the following:

Classification. The size of hydrants shall be designated by the nominal diameter of the valve opening, which must at least be 4 inches for hydrants having two $2\frac{1}{2}$-in. hose nozzles, 5 inches for hydrants having three $2\frac{1}{2}$-in. hose nozzles, and 6 inches for hydrants having four $2\frac{1}{2}$-in. hose nozzles, and shall be classed as one-way, two-way, three-way, or four-way, according to the number of $2\frac{1}{2}$-in. hose outlets for which they are designed.

The rest of the report was adopted, section by section, substantially as it came from the committee, and it was voted that the committee be continued, with instructions to confer with committees of the National Fire Protection Association and the American Water Works Association, with the view of securing uniform hydrant specifications.

WORCESTER, June 24, 1914.

The June meeting of the New England Water Works Association was held at Worcester, Mass., on June 24, 1914.

The following members and guests were present:

Members.

J. M. Anderson, G. W. Batchelder, W. U. C. Baton, A. S. Blackmer, J. W. Blackmer, C. A. Bogardus, J. Burnie, R. C. P. Coggeshall, J. E. Conley, F. W. Dean, J. M. Diven, J. Doyle, E. D. Eldredge, G. F. Evans, G. H. Finneran, T. C. Gleason, H. T. Gidley, P. Gear, F. E. Hall, D. A. Heffernan, A. C. Howes, J. A. Hoy, J. L. Hyde, A. W. Jepson, W. Kent, A. C. King, G. A. King, H. M. King, F. A. McInnes, W. A. McKenzie, H. McLean, J. Mayo, G. F. Merrill, H. A. Miller, J. W. Moran, A. S. Negus, J. A. Newlands, J. J. Philbin, S. H. Pitcher, W. H. Pitman, P. R. Sanders, H. W. Sanderson, C. D. Sharpe, G. H. Shaw, S. Smith, E. L. Stone, W. F. Sullivan, R. C. Sweetser, E. J. Titcomb, C. H. Tuttle, W. H. Vaughn, J. H. Walsh, R. S. Weston, W. J. Wetherbee, J. C. Whitney, F. B. Wilkins, F. I. Winslow, I. S. Wood, L. C. Wright. — 59.

Associates.

Chapman Valve Manufacturing Co., by J. T. Mulgrew; Hersey Manufacturing Co., by S. B. Greene; Lead Lined Iron Pipe Co., by Thomas E. Dwyer; Leadite Co., by C. A. Vance; Ludlow Valve Manufacturing Co., by A. R. Taylor and G. A. Miller; H. Mueller Manufacturing Co., by G. A. Caldwell; National Meter Co., by J. D. Lufkin; Rensselaer Valve Co., by C. L. Brown; A. P. Smith Manufacturing Co., by D. F. O'Brien and F. L. Northrop; Union Water Meter Co., by Edward Otis and D. K. Otis; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison. — 16.

Guests.

Mrs. Geo. A. King, Miss L. C. King, Mr. and Mrs. W. B. Dean, Taunton, Mass.; W. L. Venuard, Lynn, Mass.; Mrs. Wm. F. Sullivan, Nashua, N. H.; Mrs. John Mayo, Miss Hopkins, Bridgewater, Mass.; R. J. McIntyre, N. E. Mather, P. J. Cannon, N. L. Howe, Clinton, Mass.; Mrs. F. A. McInnes, Mrs. H. A. Miller, Miss Joan M. Ham, Boston, Mass.; F. W. Dinwiddie, Gardner, Mass.; Mrs. Patrick Gear, Mrs. M. C. McLean, Miss Ellen Hanley, Marion McLean, Alphonse La Porte, Leo Bacon, Mrs. Hanley, Holyoke, Mass.; W. T. Dotten, Winchester, Mass.; Neddie Eldredge, Onset, Mass.; Mrs. G. E. Batchelder, Jos. Brosanan, Harold L. Hall, Frank H. McCormick, Edmund R. Garvey, Worcester, Mass.; Mrs. John E. Gleason, Ware, Mass.; Mrs. Willard Kent, Narragansett Pier, R. I.; Mrs. J. L. Boady, Chicago, Ill.; Chas. F. Glavin, Donaldson Iron Co., Emaus, Pa.; P. R. Cashin, Boston, Mass.; Nathan C. Rockwood, *Engineering News;* Mrs. H. M. King, Springfield, Mass.; Geo. C. Hunt, Mrs. Geo. C. Hunt, John E. Washburn, Geo. E. Adams, Clarence M. Hall, Henry C. Page, Peter G. Holmes, Robert F. Batchelder, Michael J. Keernan, A. S. Pero, P. M. Shea, A. D. Bates, Miss May Brenner, his Honor Mayor Wright of Worcester. — 51.

Members and guests left the Worcester Union Station in special trolley cars and motors for the Pine Hill Reservoir of the Worcester Water Supply, in process of construction; after inspection of the reservoir the party were conveyed to Lake Quinsigamond, where lunch was served at the club house of the Tatassit Canoe Club. Following lunch, addresses were made by the mayor of the city and others.

After a short business meeting, applications for membership properly endorsed and recommended by the Executive Committee were received from C. J. Callahan, Lewiston, Me.; August V. Graf, St. Louis, Mo.; C. T. Henderson, Milwaukee, Wis.; Fred O. Stevens, E. Weymouth, Mass.; D. A. Reed, Duluth, Minn.; The Cutler Hammer Mfg. Co., Milwaukee, Wis. They were by unanimous vote made members of the Association.

Members then availed themselves of the opportunity to witness the operation of the Austin trenching machine and to inspect the shops of the Water Department and their equipment.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Boston, Mass., Wednesday, April 15, 1914.

Present, President Frank A. McInnes, William F. Sullivan, Robert J. Thomas, Samuel E. Killam, Lewis M. Bancroft, George A. King, and Willard Kent.

Twelve applications for membership were received, viz.:

Wallace Willett, mechanical engineer, 100 William St., New York, N. Y.; Charles H. Mitchell, consulting engineer, Toronto, Ont.; A. N. Beer, assistant engineer water works, Ottawa, Ont.; F. L. Fellowes, engineer water works, Vancouver, B. C.; Fred L. Cushing, water registrar, Medford, Mass.; Charles H. Smith, engineer Associated Factory Mutual Fire Insurance Company, Boston, Mass.; Walter H. Merchant, Jr., engineer of fire apparatus, Fire Department, New Bedford, Mass.; Henry T. Gidley, superintendent Fairhaven Water Company, Fairhaven, Mass.; Edward C. Sherman, consulting engineer, 6 Beacon St., Boston, Mass.; Fred A. Darling, superintendent water works, Franklin, Mass.; Herbert L. Sherman, president New England Bureau of Tests, Inc., 12 Pearl St., Boston, Mass.; Louis K. Rourke, commissioner of public works, 6 Wayne St., Roxbury, Mass.;

and the applicants were by unanimous vote recommended therefor.

Adjourned.

WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association was held at the Tatasit Club, Worcester, Mass., June 24, 1914.

Present: President Frank A. McInnis, and members William F. Sullivan, James W. Blackmer, George A. King, and Willard Kent.

Six applications were received, four for active membership, one for reinstatement, and one for associate, respectively:

C. J. Callahan, clerk water board, Lewiston, Me.; August V. Graf, assistant chemist St. Louis Water Works, St. Louis, Mo.; C. T. Henderson, electrical and mechanical engineer, P. O. Box 1564, Milwaukee, Wis.; Fred O. Stevens, superintendent water works, 114 Hawthorn St., E. Weymouth, Mass.; D. A. Reed, manager Water and Light Dept., Division of Public Utilities, Duluth, Minn.; The Cutler Hammer Mfg. Co., Milwaukee, Wis.; and the applicants were unanimously recommended for membership.

Adjourned.

WILLARD KENT, *Secretary.*

Table of Contents.

NEW ENGLAND WATER WORKS ASSOCIATION.

AUGUST, 1914.

COMMITTEE ON METER RATES.

The Committee on Meter Rates requests that members of the Association plot such meter rates as they are interested in on the attached sheets and return them to the secretary or the editor of the Association.

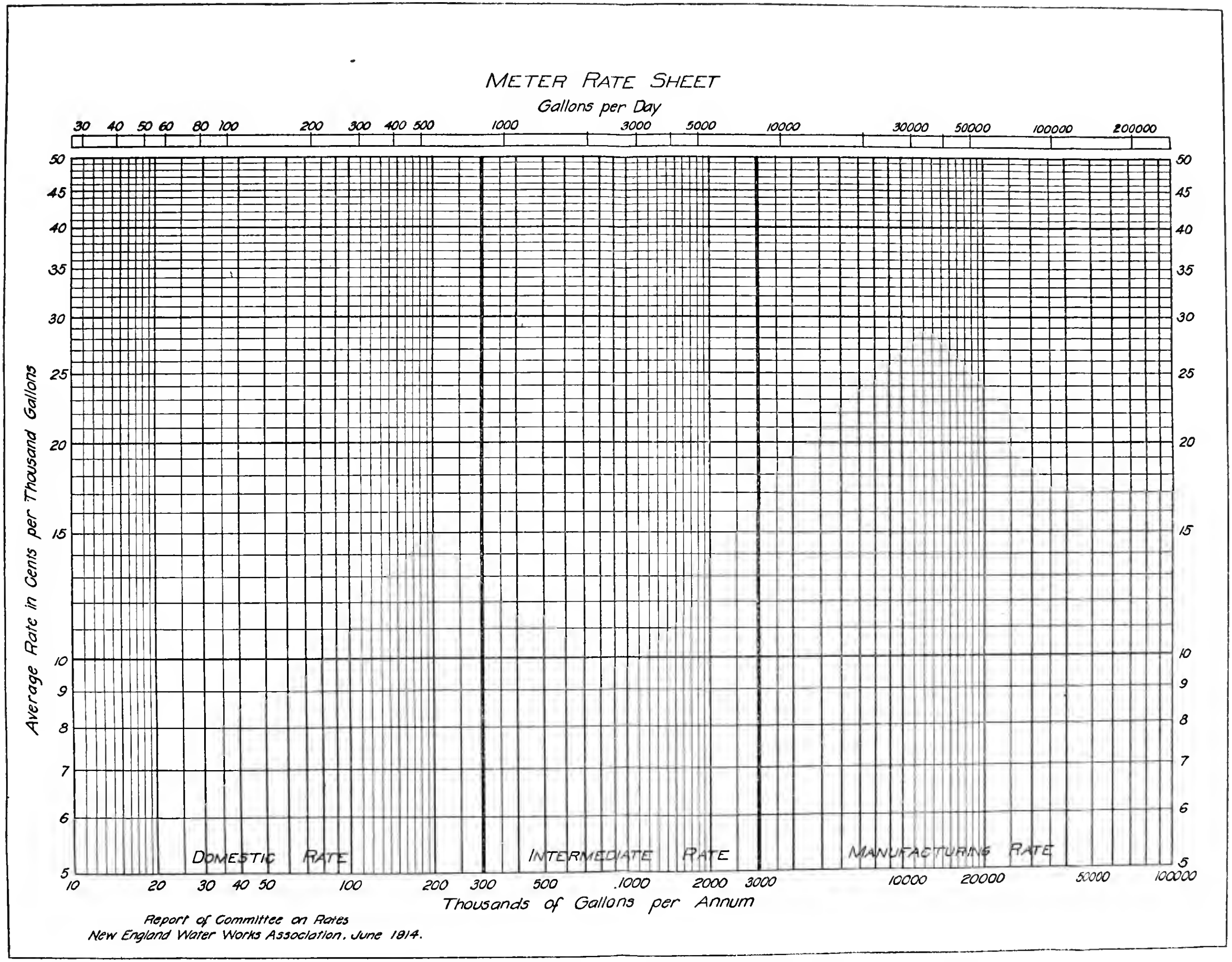
The following description is taken from the report of the committee, which is to be presented at the September Convention:

METER RATE SHEET.

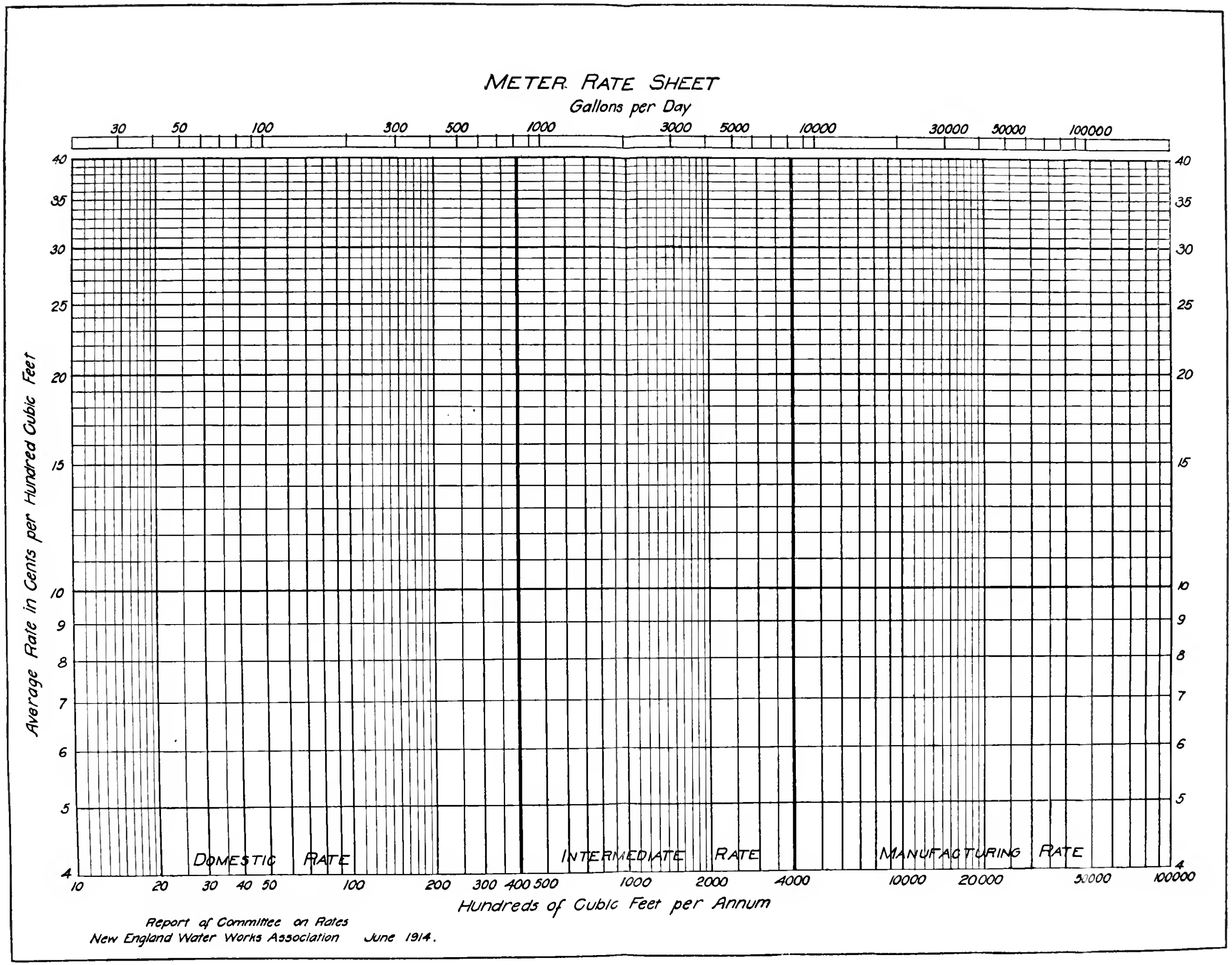
As a convenient means of plotting meter rates and of serving as a basis for comparing the rates in different cities, and of comparing proposed rates with present rates, a meter rate sheet has been prepared on which may be conveniently plotted the average rates paid by consumers drawing different quantities of water per annum. This sheet has a logarithmic scale which permits all the quantities and rates occurring in ordinary practice to be shown with sufficient accuracy in a relatively small size. This sheet has been drawn in two forms, one for cubic feet and the other for gallons. In all other respects the sheets are the same and are interchangeable. In order to plot a schedule of meter rates, a list of quantities per annum ranging from the smallest to the largest is taken, and the payment for each is computed. If the bills are made quarterly, the quantities in the list are divided by 4; or if monthly, by 12. If necessary the quantities are changed from cubic feet to gallons. The rates of the schedule are then applied to these quantities. If upon a monthly basis, the monthly bill is multiplied by 12 to produce the annual pay-

ment for that quantity of water. If a discount for cash is allowed, 0.9 of it is deducted on the assumption that 0.9 of the customers will avail themselves of it. From the sum so found is deducted 10 per cent. of the average investment of the works in service pipe and meter, if any. The remainder represents the return to the works for the assumed quantity of water. This is divided by the quantity of water for which the calculation is made. The result is the average price per thousand gallons (or per hundred cubic feet) paid by a consumer drawing that quantity in the course of a year. When the average cost corresponding to each term in the series of quantities has been found, they are plotted upon the paper and the points are connected up by straight or curved lines.

The committee suggests that blank sheets be printed and sent to every member of the Association with the request that rates of works in which he is interested be plotted and that blueprints of them be returned to the committee.



METER RATE SHEET
Gallons per Day
30 40 50 60 80 100 200 300 400 500 1000 3000 5000 10000 30000 50000 100000 200000
Average Rate in Cents per Thousand Gallons
50 45 40 35 30 25 20 15 10 9 8 7 6 5
DOMESTIC RATE
INTERMEDIATE RATE
MANUFACTURING RATE
10 20 30 40 50 100 200 300 500 1000 2000 3000 10000 20000 50000 100000
Thousands of Gallons per Annum
Report of Committee on Rates
New England Water Works Association, June 1914.


METER RATE SHEET
Gallons per Day
30
50
100
300
500
1000
3000
5000
10000
30000
50000
100000
Average Rate in Cents per Hundred Cubic Feet
40
35
30
25
20
15
10
9
8
7
6
5
4
DOMESTIC RATE
INTERMEDIATE RATE
MANUFACTURING RATE
10
20
30
40
50
100
200
300
400
500
1000
2000
4000
10000
20000
50000
100000
Hundreds of Cubic Feet per Annum
Report of Committee on Rates
New England Water Works Association June 1914.

New England Water Works Association.

ORGANIZED 1882.

Vol. XXVIII. September, 1914. No. 3.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

REPORT OF COMMITTEE ON METER RATES.

[*Read September 9, 1914.*]

TO THE NEW ENGLAND WATER WORKS ASSOCIATION:

Your Committee on Meter Rates presents the following preliminary report with the request that it be made the subject of general discussion, and with a view to the preparation of a final report by the committee after it has had the benefit of such discussion by the members.

REPORT.

Nine years ago a committee, of which the late Freeman C. Coffin was chairman, presented a most admirable report on the subject of meter rates.* This report took up the matter in a thoroughgoing and logical manner, and the justice of the method proposed has been generally recognized. The basis of the method consisted in a flat meter rate for all quantities to be made in addition to a service charge, the latter depending upon the frontage of the property. The service charge was to be collected in all cases whether water was drawn through the meter or not. In connection with this service charge, which would give the works an assured income, the rates for metered water could obviously be much lower than would otherwise be possible. These

* JOURNAL N. E. W. W. ASSOC., *19*, 1905, p. 322.

principles have found application in part in many of the water rates that have been adopted in the last years.

On the other hand, some of the methods proposed in the Coffin report differed radically from current practice. This was especially true of that portion of it which made the service charge dependent upon frontage. To adopt this method would make a fundamental change in the basis of existing rates.

Notwithstanding a general recognition of the excellence and justice of the method, the radical change involved in adopting it has served to prevent its general use. With a few unimportant exceptions it has not been adopted.

The matter is now taken up by your committee with the thought of presenting a procedure embodying the most useful features of the Coffin report, but arranged so as to diverge less from current practice, and so that the proposed schedule may be adopted with a minimum disturbance to existing rates and conditions.

To carry out this idea, your committee suggests a standard schedule in a form given below, which it believes to be adapted to general use. The committee suggests that this schedule be freely discussed by the members of the Association and modified as found desirable after such discussion, and finally, that it be adopted by the Association as a standard schedule representing an ideal towards which members may work whenever meter rates are being revised, and which may be incorporated in whole or in part as may be found feasible and advantageous in such revised rates.

In this schedule the sliding scale of rates is recognized, and three rates are provided. The schedule does not fix these rates. They are left to be fixed for each case as may be necessary to produce the required revenue. The quantities of water per annum, per quarter, or per month to which the three rates are applicable are defined and made uniform by the schedule.

In addition, a service charge is provided. The service charge was an essential feature of the Coffin schedule, but the service charge now proposed rests upon a different basis and one which the committee believes will more readily lend itself to adjustment to existing conditions.

In the event of there being local objection to using a service

charge, the committee proposes an alternate arrangement, under which the amount of the service charge is applied as a loading to the price for a small amount of water first sold from each service, thus making in effect a fourth and higher rate, for use only where no service charge is made.

DIVISIONS OF THE SLIDING SCALE.

It is proposed to make only three divisions of the sliding scale. At the present time there are many schedules in effect, with more and even with several times this number of divisions. The committee believes that in general more than three divisions are unnecessary and undesirable. Too many rates add to the complexity of the schedule, to the labor of applying it, and to the difficulty of understanding and comparing rates.

The committee proposed that all water up to 300 000 gal. per annum (equal to 822 gal. per day, or to 40 000 cu. ft. per annum, or 10 000 cu. ft. per quarter) shall be charged for at the first or highest rate. This rate for convenience will be called the Domestic Rate. The quantities of water covered by it will include substantially all water used by private residences, and also much of the water used by small hotels and smaller commercial and industrial establishments.

The second or Intermediate Rate will apply to quantities in excess of 300 000 gal. per annum up to 3 000 000 gal. per annum.

The third and lowest rate will be called the Manufacturing Rate and will apply to all water in excess of 3 000 000 gal. per annum from any service (equal to 8 220 gal. per day, or to 400 000 cu. ft. per annum, or 100 000 cu. ft. per quarter).

It is recommended that the price per 1 000 gal. or per 100 cu. ft. be, in most cases, an even number of cents, omitting fractions, and that the intermediate price for water be to the nearest cent midway between the average and the mean proportional of the domestic rate and the manufacturing rate. By this rule the intermediate rate is definitely fixed at an amount midway or a little below midway between the domestic and manufacturing rates. There is, therefore, no need of discussing the amount of this rate. Consideration may be concentrated on the two main points in the schedule, the domestic rate and the

manufacturing rate; and with these fixed, the intermediate rate will follow by fixed rule, and will be certain to be appropriate in connection with the others.

AS TO THE AMOUNT OF SLIDE IN THE SCALE.

There are many scales of meter rates in effect at the present time in which the highest rate charged for the first water is unduly large in comparison with the lowest rate charged for the largest quantities. It sometimes happens that there is a ratio of ten to one or more between these rates. The committee disparages so great an amount of slide, and recommends that the lowest price for water shall rarely be less than half of the domestic rate.

Where the price for manufacturing water is 75 per cent. or more of the domestic rate, it is suggested that the intermediate rate may be omitted and that the manufacturing rate then apply also to the water that would otherwise be sold at the intermediate rate. If the rate for manufacturing water is 100 per cent. of the domestic rate, both limits disappear and one flat rate will apply to all quantities.

Many works now make a flat rate for water. A flat rate with no slide was recommended in the Coffin report. A flat rate can only be fairly applied in connection with a proper service charge. With an adequate service charge, the reason for the sliding scale is greatly reduced, and there is much to be said in favor of the flat rate. The committee does not wish to urge the sliding scale in preference to flat rates where such are now used, and the proposed scale lends itself to use either with or without the sliding scale.

The principal reason for the sliding scale is that it costs more to distribute water to many small takers than to a few large ones. From the standpoint of cost only, the best way to take care of this excess cost is by means of the service charge. But to do this adequately would mean the adoption of a service charge so large as to be burdensome to the smallest takers. These smallest takers are not profitable to the system at low rates even with such service charges as the committee now proposes. Nevertheless they must be supplied, and it seems to be a wise policy

to supply them at low rates, making the larger takers carry a proportion of the excess cost of supplying small consumers. The sliding scale affords a means and perhaps the best means of effecting this adjustment.

In view of the general use of the sliding scale at the present time, and in view also of some strong arguments in favor of a moderate amount of slide in the scale, the committee does not see its way clear to recommend giving up the sliding scale, and only recommends that the amount of slide be limited to moderate proportions and that the points where change in rate takes place be made definite and uniform.

SERVICE CHARGE.

The committee believes that it is essential to make a substantial service charge in order to secure equitable rates for all. The service charge may be naturally made up of several parts. It suggests that the procedure to be followed in determining the amount of the service charge be as follows:

First, that the average amount of money invested by the works in the service pipe and meter be ascertained. Where the works furnish the service pipe to the curb line, and the meter, the normal cost seems to be about $25 per service. Where the taker pays for the service pipe and the works furnish the meter, the normal cost seems to be about $10 for a $\frac{5}{8}$-in. meter in position. The committee suggests that 10 per cent. of this cost be taken as the first part of the service charge. That is to say, that $2.50 per annum be used where both service and meter are paid for by the works; $1.00 per annum where the meter only is furnished by the works, and that this part of the charge disappear where both pipe and meter are paid for by the taker. The committee believes that on the whole 10 per cent. is a fair allowance for the depreciation in the service pipe and meter, and for the interest on the money invested in them. The structures are not long-lived, and occasional repairs are needed. A reasonably approximate figure is sufficiently close, and 10 per cent. is used in this way.

The figures mentioned for cost of service and meter are believed to be representative, but they should be increased or de-

creased according to the ascertained average costs under local conditions. Round figures should be used in all cases as a matter of convenience, and because precision is unnecessary, and because it cannot be reached in most cases. For meters larger than the five-eighths domestic size, correspondingly larger figures should be used.

Second, a sum per annum representing approximately the cost of reading the meters, keeping the meter records, making bills, and collecting the money. The amount of this item depends upon the frequency upon which meters are read, and upon local conditions; for ordinary domestic services where meters are read once a quarter, $1.00 per annum may be a sufficient allowance. This figure may also be used without substantial injustice for services of all sizes, because when meters are read monthly the quantities are usually larger and the cost of meter reading becomes an inappreciable fraction of the bill.

Third, an amount which will represent the approximate average value to the works of the water that passes a domestic meter without being registered. The normal service of a domestic meter for one day may be assumed to consist of passing 200 gal. of water, more or less, in about two hours, the whole time being made up of many short intervals during the day. During the remaining twenty-two hours no water will ordinarily be flowing. If the service pipe and plumbing are perfectly tight, no water will pass during those twenty-two hours; if there is a leak of such size that the water lost by it will turn the meter, then the meter will register the flow throughout the twenty-four hours, and all the water passing will be recorded, except that there may be some slip in the meter at a low rate. If there is a leak in the service or plumbing which allows water to escape, but in amount so small that it does not serve to move the disk or piston of the meter, then the amount of water lost by such leakage in the twenty-two hours when the piston or disk is not moving will be entirely unrecorded. Probably no meter in ordinary service will register a flow of less than 100 gal. in 22 hours. Many meters in actual service will allow much larger quantities to pass without registering. It is probable that the plumbing in every house has leaks at times, through defective washers in

the faucets or automatic valves which permit the loss of water in amounts too small to be recorded. In some houses such loss is always taking place. In the aggregate the amount of this unrecorded leakage from plumbing is large. It probably furnishes the greatest single reason why the amount of water registered by meters never approximates closely the total quantity of water furnished by the system.

Water lost in this way is running at a steady rate throughout the twenty-four hours, and increases but slightly the peak load of the plant. It can, therefore, be supplied at the lowest relative cost, and for the purpose of this estimate should be reckoned at the lowest rate charged for any water that is sold.

The amount lost per service will range from nothing to 100 gal. per day, and occasionally to much larger quantities. Assuming an average of 50 gal. per day per service at a minimum price of 10 cents per 1 000 gal., the value of water so lost amounts to \$1.82 per service per annum.

There are no adequate data upon which this loss can be computed, and the committee sees no way of securing such data at this time. Nevertheless it believes that the matter is an important one and that a substantial allowance should be made for such losses. It suggests for the present the use of \$2 per annum for this item.

Upon this basis the service charge will amount to the sum of these parts, namely, first, 10 per cent. of the average investment of the works in service pipe and meter; second, \$1 per annum for reading meters, billing, and collecting; third, \$2 per annum for the probable value of unregistered water. For a domestic service with $\frac{5}{8}$-in. meter, the ordinary service charge may properly be \$3, where service and meter are paid for by the taker; \$4 where the meter is furnished by the works; and \$5 or \$6 where both meter and service pipe are paid for by the works, the lower figure being used where the average cost of a service pipe is under \$15, the higher where it is greater than \$15.

The figures used in the above paragraphs should be considered only as general approximations, to be modified to meet established local conditions, or upon more complete data. The committee suggests that the *method* is of first importance and should

be first discussed and settled, and that the values to be then used under it should always be selected with reference to the conditions in each plant for which a service charge is to be established.

The charges for larger services will readily be reached by the application of the same methods, and the committee does not suggest any values for them at this time.

AS TO THE MANNER OF APPLYING THE SERVICE CHARGE.

The committee recommends that the amount determined by the use of these methods, raised or lowered to a convenient round figure, should be charged for each service; that this charge should be made in all cases whether water is drawn or not; and that all water drawn from the service should be charged at current rates in addition thereto.

Many works at the present time make a charge for meter rent. In such cases, and otherwise if desired, the service charge may be called "meter rent," the amount being taken as the amount determined for the service charge.

The method of making a service charge separate from and in addition to the charge for water registered is the most convenient and equitable way of distributing the costs considered in the above paragraphs where they belong, and the committee recommends it for use in all cases.

ALTERNATE PROCEDURE.

Where there is local objection to making a service charge (even though called meter rent), the following alternate and less desirable procedure may be used.

The amount that would be a fair service charge is computed as above. This amount is divided by 60 and the result to the nearest even cent is added to the domestic rate, and this new rate (which may be called a loaded or maximum rate) is applied to the first 60 000 gal. of water per annum drawn from each service. If cubic feet are used, the amount is divided by 80, and the result to the nearest even cent is added to the domestic rate per 100 cu. ft., and the increased rate is applied to the first

8 000 cu. ft. per annum used from each service. In connection therewith, a minimum rate must be established. This minimum rate may be about $3 more than the computed service charge. This double procedure of loading the rate for the first quantity of water sold from each service and of establishing a minimum rate will accomplish in a rough way the general purpose of the service charge. It is less satisfactory because it is less fair as between the various small consumers drawing quantities of water that will be affected by it. It is as fair to the works and to the larger consumers because the loading of the first quantity of water sold by the method described will produce a sum nearly equal in the aggregate to that which would otherwise be directly charged for the services.

GALLONS OR CUBIC FEET.

It is most unfortunate that two units of measurement are in common use. It would be much better if one could be discarded. More than three fourths of meters now in service record the quantity in cubic feet. According to replies to the committee's inquiries, schedules of water rates are about equally divided between cubic feet and gallons. The Coffin committee recommended the use of cubic feet. The number of meters now being sold to register in gallons is increasing much faster than the total number sold. This indicates a gain in popularity of the gallon. There is much to be said in favor of each of these units. Replies to the circular letter of the committee indicated very evenly divided preference. In view of this condition, and in view of the further fact that members of the committee have different preferences, it is not thought best to attempt to recommend at this time that either unit shall be used to the exclusion of the other. The committee recommends further general discussion of this subject, and suggests after such discussions that a vote might be taken to show the preference of the members.

It is absurd that two units should continue in general use. The advantages of adopting either one would be vastly greater than any possible advantage in either. It would seem that the Association could determine which it prefers and throw its influence toward its universal adoption. The committee feels

that this should be done by action of the whole Association and not by a committee.

In the interest of economy of labor, it is obviously desirable that the same unit should be used in any system for both meter registers and schedules. Thus the use of meters reading in cubic feet, with a schedule of rates in gallons, is undesirable and should be avoided by changing as rapidly as is possible so that both are on the same basis.

FORMS OF SCHEDULE.

The committee proposes the following form for a schedule for meter rates:

For each service supplied by $\frac{5}{8}$-in. meter there shall be a charge for the service and meter per annum of	$ _____

In addition thereto, for all water drawn there shall be charged:

	Cents per 1 000 Gal.
For the first 300 000 gal. of water per annum, or any part thereof, the Domestic Rate of	_____
For water in excess of 300 000 gal. and under 3 000 000 gal. per annum, the Intermediate Rate of	_____
For water in excess of 3 000 000 gal. of water per annum, the Manufacturing Rate of	_____

The prices to be written in the schedule should be fixed in each case by the local authorities to meet local conditions, and to produce the required revenue, and the committee makes no suggestion as to how great they should be. It is further the intention that cubic feet shall be substituted for gallons if desired, the numbers being divided by 7.5, so that the actual quantities paid for under each rate will not be changed; also that the rates may be stated as semi-annual, the numbers being divided by 2; or as quarterly, the numbers being divided by 4; or as monthly, the numbers being divided by 12.

It is to be recognized that a monthly rate with one twelfth the quantities, with varying rates of monthly use, will produce in some cases slightly different annual results from the corresponding annual rate, but it is recommended that such difference be disregarded, that the rates be made for whatever period meters

are read, and that each record period be considered by itself in computing the charge.

A schedule under the alternative and less desirable arrangement, avoiding the term "service charge" or "meter rent," would read as follows:

Minimum charge for service with $\frac{5}{8}$-in. meter, per annum,	\$
	Cents per 1 000 Gal.
For the first 60 000 gal. of water per annum, or any part thereof, at the Maximum Rate of	——
For all water in excess of 60 000 gal. and under 300 000 gal. per annum, the Domestic Rate of	——
For all water in excess of 300 000 gal. and under 3 000 000 gal. per annum, the Intermediate Rate of	——
For all water in excess of 3 000 000 gal. per annum, the Manufacturing Rate of	——

METER RATES IN FORCE.

The committee asked for schedules of meter rates by a circular letter addressed to all members of the Association. A large number of rates were received from members in compliance with this request. From these rates a calculation was made of the annual charge for a quantity of 10 000 gal. drawn at a uniform rate throughout the year, and for 30 000, 100 000, etc., up to 10 000 000 gal. per annum. In computing these amounts when a discount was allowed for prompt payment, it was assumed that this discount would be claimed by 0.9 of the takers; and 0.9 of such discount was, therefore, deducted from the computed amounts. In connection with these rates a statement was obtained from each plant showing whether the service and meter were paid for by the department or by the taker, or whether its cost was divided between them, and in all cases showing the approximate average amount paid by the plant on account of each new service and $\frac{5}{8}$-in. meter. The amounts paid by different works for service and meters range from nothing to over \$50 per service. The normal cost of the service from the main to the curb line, and of furnishing and setting a meter as shown by the replies, is about \$25. The general average is

10 per cent. greater, mainly because in a few cases very high costs were reported. A great majority of replies gave average costs between \$20 and \$30; a few were under \$20, and a few between \$30 and \$50, and some were over \$50, these representing unusually difficult local conditions.

The divergence between the practice of different works in respect to bearing the cost of service pipes and meters must be taken into account in some way in order to compare properly the meter rates used in connection with them. The simplest way of doing this is to deduct 10 per cent. of the average cost to the works of each service from the amount computed by the schedule for each quantity. This course is followed and the annual rates that follow are thus reduced by an amount equal to 10 per cent. of the work's contribution to the cost of each service. Obviously in applying any rates deduced from these figures to a particular case, it will be necessary to add one tenth of the corresponding contribution to the works to the cost of services in that plant.

The committee believes that meter rates, where most of the services are metered, may be more safely taken as an indication of good practice than rates in those cities where the meter system has been used to only a limited extent. In them, most of the revenue is derived from meter rates. There have usually been discussions of the equity of the meter rates as between different classes of takers, and it may be assumed that in most cases the rates have been reduced during a term of years to fairly satisfactory shape. On the other hand, where meters are used to only a limited extent, it frequently happens that schedules of rates are in force that are not well adapted to the service, and their inconsistencies have not been removed because of the limited use that has been made of them. With this in mind, fifty representative reports were selected for study. In each of these more than 50 per cent. of the services were metered; most but not all of the selected works were in New England.

It would be unfair to speak of the results so obtained as the average meter rates for New England conditions, or of any conditions, because the rates in different works differ considerably in form and amount, and another selection of fifty cities equally representative would give somewhat different results. The

results are nevertheless believed to be in a general way representative of present practice.

An interesting comparison may be made with a compilation of meter rates by Mr. George W. Biggs, Jr., chief engineer of the American Water Works and Guaranty Company. This compilation shows the amounts that would be paid for various annual quantities of water in 146 works, about half of them municipally owned works, the others being water companies. In Mr. Biggs' figures, no deduction is made on account of the contribution of the works toward the cost of the service and meter. Obviously an allowance must be made for this item to make the results comparable with those obtained from the fifty rates investigated by your committee. In the absence of information as to what the average contribution has been, it is assumed that it has been $12.50 per service, this being about one half of the normal total cost per service, and a deduction of 10 per cent. of this, or $1.25 per annum, has been made from the figures compiled by Mr. Biggs. This correction is sufficiently close for practical purposes, and any error in it will not have an important influence on that which follows. As Mr. Biggs' quantities were not always the same as those for which the committee's calculations have been made, interpolations have been made which are sufficiently accurate.

It appears that the average amount of slide in the scale for which data were collected by Mr. Biggs, representing works all over the United States, is somewhat greater than in the fifty scales examined by your committee. For annual quantities from 30 to 300 000 gal., the average from 146 cities all over the country is distinctly higher than the average for the fifty works mainly in New England. On the other hand, with annual quantities above 1 000 000 gal., the order is reversed, and the average rates deduced from the 146 cities are lower.

On the whole, the two series of results show surprisingly little divergence. On an average, the slide begins to take place at about the same point, and except for small differences above mentioned the amount of slide is nearly the same in both cases.

It is possible to find rates to be inserted in the schedule which the committee now proposes which will produce charges for

the different amounts of water drawn corresponding approximately with those indicated by the two sets of data. Upon trial it is found that a service charge of $3 per annum (plus 10 per cent. of the cost of the service pipe and meter to the works), a domestic rate of 21 cents per 1 000 gal., an intermediate rate of 16 cents, and a manufacturing rate of 11 cents, produce amounts which fall between the two sets of data above mentioned for nearly all quantities, and correspond well with both of them.

These rates may thus be taken as representing in a general way, and with a fair degree of accuracy, the present average American practice in meter rates.

The three sets of rates are shown in the following table and graphically on a diagram. This shows the total charge in dollars per annum under domestic rates for various drafts, and also the average price per 1 000 gal. for all drafts up to ten million gallons per annum.

COMPARISON OF METER RATES.

		50 selected Works with most of their services metered, less 10 per cent. of cost of services.		146 Works compiled by Mr. Biggs, less $1.25 per service per annum.		Rate of $3 +0.21 Dom. +0.16 Inter. +0.11 Mfg.	
Annual Gallons.	Qantity. Cu. Ft.	Amount of Bill.	Cents per 1 000 Gal.	Amount of Bill.	Cents per 1 000 Gal.	Amount of Bill.	Cents per 1 000 Gal
10 000	1 330	$5.22	52.2			$5.10	51.0
30 000	4 000	7.05	23.5	$10.50	35.0	9.30	31.0
100 000	13 330	22.80	22.8	27.00	27.0	24.00	24.0
300 000	40 000	63.90	21.3	69.00	23.0	66.00	22.0
1 000 000	133 000	180.00	18.0	180.00	18.0	178.00	17.8
3 000 000	400 000	471.00	15.7	435.00	14.5	498.00	16.6
10 000 000	1 330 000	1 370.00	13.7	1 200.00	12.0	1 268.00	12.7

The committee limited its study to quantities under ten million gallons per annum with an average annual charge of about $1 300 because this limit is high enough to include all but a very few of the largest takers. Special considerations often control the rates made to those using more than this amount of water. These considerations are always of local character, and the committee has not thought it necessary to extend its study to existing rates for larger quantities.

It suggests tentatively that if it is thought necessary to make a fourth and lower rate that it be called a *special rate*, and that

it be made to apply only to quantities in excess of 30 000 000 gal. per annum.

METER RATE SHEET.

As a convenient means of plotting meter rates and of serving as a basis for comparing the rates in different cities, and of comparing proposed rates with present rates, a meter rate sheet has been prepared on which may be conveniently plotted the average rates paid by consumers drawing different quantities of water per annum. This sheet has a logarithmic scale which permits all the quantities and rates occurring in ordinary practice to be shown with sufficient accuracy in a relatively small size. This sheet has been drawn in two forms, one for cubic feet and the other for gallons. In all other respects the sheets are the same and are interchangeable. In order to plot a schedule of meter rates, a list of quantities per annum ranging from the smallest to the largest is taken and the payment for each is computed. If the bills are made quarterly, the quantities in the list are divided by 4, or if monthly, by 12. If necessary the quantities are changed from cubic feet to gallons. The rates of the schedule are then applied to these quantities. If upon a monthly basis, the monthly bill is multiplied by 12 to produce the annual payment for that quantity of water. If a discount for cash is allowed, 0.9 of it is deducted on the assumption that 0.9 of the customers will avail themselves of it. From the sum so found is deducted 10 per cent. of the average investment of the works in service pipe and meter, if any. The remainder represents the return to the works for the assumed quantity of water. This is divided by the quantity of water for which the calculation is made. The result is the average price per thousand gallons (or per hundred cubic feet) paid by a consumer drawing that quantity in the course of a year. When the average cost corresponding to each term in the series of quantities has been found, they are plotted upon the paper and the points are connected up by straight or curved lines.

On Fig. 1 presented herewith are plotted the averages of the rates in the fifty cities considered by the committee and in the 146 cities compiled by Mr. Biggs, and also those correspond-

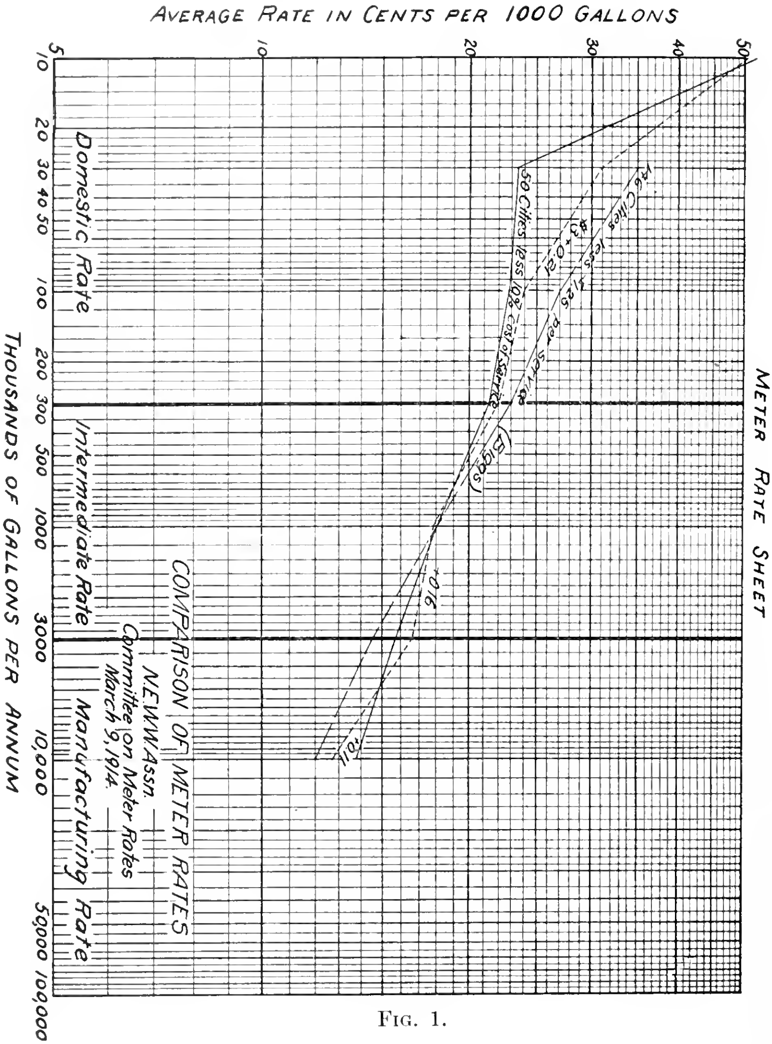


FIG. 1.

ing to a service charge of $3, plus 10 per cent. of the cost of the service, with 21 cents per thousand gallons for domestic, 16 cents for intermediate, and 11 cents for manufacturing rates.

On Fig. 2 are plotted nine representative schedules from New England cities. It is seen from these that in most cases

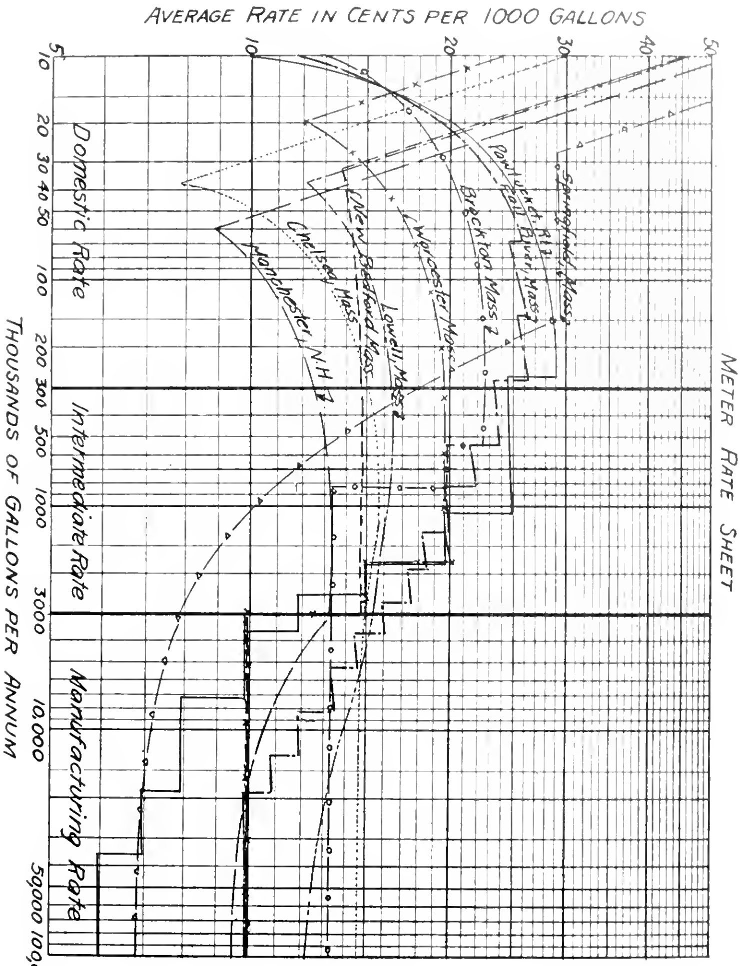


FIG. 2.

there is some point with a relatively small quantity of water, usually between 20 000 and 60 000 gal. per annum, where present rates are lower relatively than for either smaller or greater quantities. This point comes in most cases at the end of the minimum rate, that is to say, for a consumer that pays the minimum rate and draws the maximum quantity of water permitted under it.

Such consumers at present are paying substantially less with reference to the whole cost of the service than are consumers who take either less water or more water. Some of the rates now in force do not show this low point.

The committee suggests that blank sheets be printed and sent to every member of the Association with the request that rates of works in which he is interested be plotted and that blueprints of them be returned to the committee.

GRADUAL ADOPTION INTENDED.

It is undesirable that meter rates be changed often, and it is not to be expected that existing rates will be at once replaced. On the other hand, existing rates, even some of the best, have illogical and unreasonable features. The innumerable divergencies in forms of present rates are unfortunate and undesirable. The committee believes that the adoption by this Association of a standard form of schedule will be of substantial assistance to its members in bringing about methods that are both more uniform and more reasonable.

Respectfully,

(*Signed*) ALLEN HAZEN, *Chairman*.
CHARLES R. BETTES.
A. E. BLACKMER.
A. W. CUDDEBACK.
JAMES L. TIGHE.
PHILANDER BETTS.

DISCUSSION.

THE PRESIDENT. We have listened to another report of a kind that has given our Association its prestige, and, as Mr. Hazen has suggested, a free and full discussion is most desirable.

MR. J. M. DIVEN. Do I understand that with the sliding scale all consumers pay the same amount for the first 300 000 gal., whether they come under the manufacturer's rate or not?

MR. HAZEN. They do.

Mr. Diven. Isn't the intermediate rate a little large? Doesn't that make a manufacturer pay first and second rates up to 10 000 gal. a day, which is as much water as an ordinary small factory would use? How is the intermediate rate arrived at?

Mr. Hazen. The intermediate rate is nearly midway between the domestic and manufacturing rate, and is determined by a fixed rule so that there can be no discussion as to what the intermediate rate should be after the others are arrived at, and it will always harmonize with the others.

Mr. Arthur E. Blackmer. There is one point that I would be very much interested in hearing the members discuss, and that is as to the value of water lost through the non-registration of meters. I think there was some difference of opinion among the members of the committee on that. The estimate of $2 in the report seems to me somewhat high, and I would be interested to hear what men who have had a good deal more experience than I in the care and handling of meters say on that question.

Mr. Diven. It seems to me that is a pretty hard matter to determine. The only data we have is the loss in meters as they are tested. Of course, a meter when it is taken out and tested, after it has been in use for two years, would show a loss at that time which would not be a fair average of what it has been losing during its life. Probably when it was a new meter it lost very little. Possibly one way to arrive at it would be to take the new meter as showing no loss, and the tested meter after one or two years as, say, 10 per cent., or whatever it might be, and taking that as an average.

Mr. Hazen. Mr. Bettes, a member of the committee, engineer of the Queen's County Water Company, made some observations on meters and services and gave the committee results that were the basis for that part of the report. He found that no meter ordinarily, even a brand new one, would register less than 100 gal. per day. That is something for our meter men to discuss, and I would like to hear from them on that question. But if a meter will not register 100 gal. per day, and there should be a leak in the plumbing of any amount up to 100 gal. per day, then during all the part of the twenty-four hours when no other water is being drawn, the meter will give absolutely no record of it.

Mr. Arthur A. Reimer. Those of us who are in the game directly handling meters must have found that 100 gal. per day is pretty well below the limit of a majority of meters. After handling several thousand meters I feel that the committee has not gone a bit too high in putting an average of 50 gal. per day for the leakage account, and I think they could safely go higher than that, if the experience we have had is any criterion. There is a difference in meters, as we all know, — surely in the different makes of meters, — and on comparing the specifications in different cities you will find that the leakage test, as it is called, varies anywhere from 10 gal. per hour to perhaps 20 or 25 gal. per hour. The meters are allowed a pretty large leeway even on that test, and a good many of them fall down.

Speaking to the first part of the report, I think that the committee is working along a very wise line in recommending that fewer steps be made in the sliding scale, wherever the sliding scale is used. Without throwing any bricks at anybody, I have been quite amused, to put it mildly, at the numerous steps in some sliding scales. I am not criticising any one, because the local conditions may have made it seem wise to adopt a many-step scale. But the clerical work involved in a scale with many steps must be very much greater than in the case of one, we will say, with three steps, such as the committee has advocated; and, furthermore, the adoption of a fairly high amount for the first step is in the right line, I think, also, because I should say that in 90 per cent. of the cities of the country we will find that the use in 75 per cent. of the individual cases will fall within that first step, thereby again decreasing the clerical work involved. I think that the committee is on the right line in that particular.

Mr. R. C. P. Coggeshall. Mr. President, I for one have felt that the unit should be the same to all takers. We had a very queer schedule of rates in our city a few years ago, and it was finally determined to make one rate flat, and the meter rate was established at 15 cents per thousand gallons. That obtained for over a year, everybody being satisfied, with the exception of the manufacturers. They came in and wanted lower rates, and finally the concession was made to them that for manufacturing purposes the rate should be 10 cents, and for everything else 15 cents.

That is the present established rate in New Bedford for the two units. So far as the registration is concerned, we call it 15 cents per thousand gallons, but all the bills are made out in cubic feet, at $1.12 per thousand cubic feet, or 75 cents, as the case may be. All the water that is used within a manufacturing enclosure we consider as used for manufacturing. We have now every service in New Bedford metered, and that produces a revenue which just about pays our expenses. I hope the time will come when we can put the meters in without making an extra charge for them, but we now make a rental charge. Mr. Whipple calls my attention to the fact that our dividing line is exactly the same as the committee has recommended.

Mr. G. F. Merrill. The question has been brought up as to whether it is customary, when several services are owned by the same property owner, to put those on the sliding scale. That is a matter which comes up sometimes with us.

The President. In Boston we oftentimes make an aggregate of all the water used within one enclosed area. For instance, if there is a fence surrounding half a dozen buildings, we would take the aggregate of the water used and apply the sliding scale. This report is of such unusual value that it would seem to me discussion might well be postponed until our November meeting.

Mr. William F. Sullivan. I move that the further discussion of the reports of the Committee on Statistics of Filter Operation and on Meter Rates be postponed until the November or December meeting, or until such time as the reports can be printed and copies be sent to all the members, so that we may get the benefit of written as well as oral discussion.

(Adopted.)

REPORT OF COMMITTEE ON STATISTICS OF WATER PURIFICATION PLANTS.

[*Read September 9, 1914.*]

To the Members of the New England Water Works Association:

On October 8, 1913, the undersigned were appointed as a committee to consider the subject of "Statistics of Water Purification Plants" and to recommend certain standard forms for reporting such statistics. Your committee has held several meetings and devoted considerable time to the subject, but is not ready at this date to make a final report, but merely a report of progress.

We have divided the subject into five topics. The present report deals with only the first two of these, and with these only in a preliminary way.

Believing that before any form of statistics is adopted it should be fully discussed by those most interested in the matter, we have prepared certain tabular forms for recording the results of analysis, which we beg to submit for discussion and criticism. We hope to be able to present a final report at the next annual meeting of the Association.

George C. Whipple, *Chairman.*
Robert Spurr Weston, *Secretary.*
F. D. West.
Frank W. Green.
E. E. Lockridge.

August 17, 1914.

REPORT OF COMMITTEE ON STATISTICS OF WATER PURIFICATION.

The studies which have been made by the committee may be considered under the following heads:

A. Descriptive data.

B. Statistics of analysis.

C. Engineering statistics.

NOTE.

This report will be open for discussion at a future meeting which will be announced later. All members having information pertaining to this subject, who are not able to attend this meeting, are urged to send it to the Editor for publication.

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REPORT OF COMMITTEE ON STATISTICS OF WATER PURIFICATION.

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A. Descriptive data.
B. Statistics of analysis.
C. Engineering statistics.

D. Financial statistics.

E. Vital statistics.

A. DESCRIPTIVE DATA. The number of water-purification plants in the United States to-day is very large, and during each year new plants are constructed. Descriptions of the most important plants have been published and may be found scattered through engineering papers, magazines, and official reports. When reading these, it is found that a number of important facts are omitted. So numerous are these omissions that it is impossible from the published descriptions to make compilations of even the most general data which will be adequate. Thinking that it would be of service to those preparing descriptions of filter plants for publication, the following schedule of desirable data has been prepared. Further details would be useful in many cases, but the following items in connection with the study of the operation of a purification plant are always important:

1. City or town, and population at last census.
2. Name of owner.
3. Name of designer.
4. Date when plant was put into service.
5. Total cost, with statement as to what is included.
6. Source of supply.
7. Rated capacity.
8. Method of purification.
9. Total capacity of subsiding or coagulating basins.
10. Total capacity of filtered water basin.
11. What chemicals are used.
12. Where chemicals are applied.
13. How applications of chemicals are made.
14. Number of filter units.
15. Net area of filter surface.
16. Depths of filtering materials.
17. Sizes of filtering materials.
18. For slow filters, — arrangements for cleaning sand surface, sand handling, sand washing.
19. For mechanical filters, — method of cleaning filter beds.
20. Number of subsiding or coagulating basins.
21. How the rate of filtration is controlled.

B. Statistics of Analysis. Through the efforts of the American Public Health Association, the methods of water analysis used in North America are now on a fairly uniform basis. The practice of expressing the results of chemical analysis in parts per million is almost universal and the methods employed are coming more and more into agreement.

Blanks have been prepared illustrating the committee's recommendations regarding the form of report, the tests to be made, and the method of expressing the results. These blanks are as follows:

Table 1. Chemical and Microscopical Character of Raw Water.
Table 2. Turbidity and Color of Raw Water.
Table 3. Bacteria in Raw Water.
Table 4. Chemical Character of Water Delivered to Mains.
Table 5. Turbidity and Color of Water Delivered to Mains.
Table 6. Numbers of Bacteria in Water Delivered to Mains.
Table 7. Numbers of B. Coli in Water Delivered to Mains.

All of the above tables are arranged to show the analytical data by months and years.

The elimination of unnecessary analytical work is a matter that needs consideration at this time quite as much as the making of the necessary tests. Laboratory practice at various purification plants has shown that many of the determinations which are ordinarily included in the standard water analysis schedule are here of little or no importance. For example, the determination of nitrogen in the usual forms of free and albuminoid ammonia, nitrites, and nitrates serves no particular purpose in water purification except in special cases. They neither assist the superintendent in the operation of the filter, nor give any adequate idea of the safety of the filtered water. On the other hand, some of the simpler physical tests, such as numerical determinations of turbidity, color, and odor, microscopical examinations and tests for alkalinity, iron, and carbonic acid, have come to be regarded as most valuable; and in special cases various other tests, such as dissolved oxygen and manganese. Bacteriological tests are of course important.

One step in making an analysis of water has never received half the attention that it deserves, namely, sampling. Of what value is it to use analytical methods of great refinement if the samples

themselves are not representative, if the mass of water from which the sample is taken is not homogeneous, or if the water changes in character from one day to another? Samples for chemical analyses are almost never larger than 4 liters (1 gal.); and samples for bacteriological analyses are seldom larger than 100 c.c. (4 oz.), while the quantities actually used for the different tests are still smaller. In counting the number of bacteria, the quantity used is less than a thimbleful.

On the other hand, we know that bodies of water are not homogeneous. In a lake or settling basin there are vertical and lateral variations; a river is constantly changing, not only in volume but in the character of the water; filter effluents vary, especially the effluents from mechanical filters where the runs are short and the rates are high. The causes of these variations which affect the results of water analyses through unfair sampling are so numerous that they cannot be studied by themselves, and the only course left is to apply to them the laws of probability, or, in other words, to arrange the data secured in some such way that the importance of the inevitable variations may be indicated and an index of the character of the water examined be obtained.

Thus we see that a question of fundamental importance is that of frequency of collecting samples. The question is, How often must samples be taken to obtain reliable results? As a general proposition it may be stated that the frequency of sampling should depend upon the frequency of change in the character of the water examined. For a water of constant quality, a few samples taken at infrequent intervals may serve to give a fair idea of the water, but if a water be subject to great fluctuations in character, a few samples taken at long intervals might or might not give a fair idea of the water. The reliability of the average result will be determined by the laws of probability. The average result does not tell the whole story, for it eliminates the individual results, and a water supply should be safe and wholesome all of the time.

The frequency of sampling has a limitation, which is controlled by practical and financial considerations. In a small plant the cost of daily analyses would usually be prohibitive, and even weekly analyses might be a burden. It would be recognized, however, that results based on infrequent samples are less valuable than

those based on frequent samples; and that irregular sampling gives the most unreliable results. In order to emphasize this point it seems desirable to establish certain grades of control of operation, based upon the character of the records kept, as follows:

First Grade: Water purification plants under first-grade supervision are those where analyses of the filtered water are made one or more times a day, and where engineering and such other data regarding the operation of the plant as are necessary are collected by one or more attendants constantly employed.

Second Grade: Water purification plants under second-grade supervision are those where analyses are made regularly, say once a week or once a month by a trained analyst, and where an attendant constantly on duty makes simple daily tests.

Third Grade: Filter plants under third-grade supervision are those where analyses are made irregularly and infrequently, and where no daily tests are made by the attendant.

Sometimes it is difficult to grade the supervision given a plant. As an example we have the Lawrence city filter, where daily tests are made during five winter and spring months of the year, and weekly tests during the remaining seven months. Here frequent analyses were made during those seasons which were most critical. This might be termed a mixed supervision of the first and second grades.

This grouping should not be considered as necessarily casting a stigma upon second- or third-grade supervision. Some water supplies may not demand first-grade records. In general it may be said that the safer the raw water, the lower may be the grade of analytical supervision. In other words, polluted waters require the purification plant to be operated with a higher factor of safety, and to this end a more careful analytical control is needed. Stored waters are safer than unstored waters, and with them a lower degree of analytical supervision may suffice. A corollary to this would be that small plants which cannot afford high-grade supervision of filters should endeavor to protect the quality of the supply by storage or by incorporating a large factor of safety in the design of the plant.

Explanation of the Terms Used.

Some explanation of the terms used in the various tables is necessary.

Test Day.

By the term " test day " is meant a period of twenty-four hours during which tests are made. This period of time seems to be the shortest period that it is practical to use as a statistical unit in determining the efficiency of water purification plants.

When more than one observation is made during a test day, the results should be combined by processes of averaging to obtain single numbers representative of the observations for that day. When this is done the fact should be so stated.

Bearing in mind that by the law of least squares the probable error of the result of a series of observations varies as the square root of the number of the observations, and assuming the precision of the results of daily sampling to be unity, then comparatively the precision of the results of weekly sampling would be only 0.38; that of monthly sampling, 0.18; and that of yearly sampling, 0.05; while the precision of hourly sampling would be 4.90.

Monthly and Annual Summaries.

For the purpose of uniform tabulation, calendar months and calendar years should be used as the basis of grouping the daily results.

Averages.

Each monthly average, or mean, should be obtained by dividing the sum of the daily results by the number of days on which tests were made during the month, that is, by the number of test days.

Strictly, the yearly average, or mean, should be obtained by dividing the sum of the daily results by the number of days on which tests were made during the year, that is, the yearly average should be the average for the twelve months weighted according to the number of test days in the month. When daily tests are made, however, this weighted average is practically the same as the simple average of the monthly results. When the number of test days in the different months varies, as in the case of a mixed record, the annual average thus computed does not give a fair

idea of the operation of the plant, as undue weight is given to those seasons when the largest number of tests are made. For this reason, and also for the sake of simplicity, the committee recommends that the annual average be taken as the mean of the twelve monthly averages.

Median.

The occurrence of occasional observations which are abnormally high often causes the average to be non-representative of the tests made during a month or year. Sometimes a single erratic test will greatly distort the average result. For this reason the median as well as the mean should be computed for each month and year.

Literally, the median is the result which lies in the middle of a series of results arranged in order from lowest to highest. That is, it is that value above and below which are an equal number of higher and lower values. For example, in the series 1, 2, 3, 8, 16, the figure 3 would be the median, while the average would be 6. To find the monthly median, arrange the daily results obtained during the month in order of magnitude. If there is an odd number of tests, select the middle term. If there is an even number, take as the median the average of the two middle terms. To find the yearly median, arrange the daily results for the entire year in order of magnitude, regardless of the month in which they occur. Do not take the average of the monthly median, or even the median of the monthly medians.

Further Statistical Analysis of Results.

The committee has considered the further analysis of the analytical data by the use of other statistical methods, but is of the opinion that these cannot be wisely adopted as standard procedures until further study of them has been made. The tables provide, however, for a classification of the data relative to turbidity, color, and number of bacteria into groups, from which further statistical studies may be made if desired. These need no special explanation.

Per Cent. of Time.

Several of the tables provide a horizontal line for the per cent. of time during which the results fall within the stated groups.

When lines are drawn through certain spaces in this and other summaries, they indicate that the spaces should not be filled out.

Precision of Analytical Methods.

Your committee has not concerned itself with methods of analysis, but recommends for the sake of uniformity that the Standard Methods of the American Public Health Association be adopted as far as practicable. Particular attention is called to the rules relating to the use of significant figures in recording the results of analyses. The following table is given for reference. The results of chemical analyses should be recorded preferably as parts per million.

Determination.	Results to be Reported.
Numbers of bacteria.	Ordinarily use two significant figures; never more than three.
Percentage of time.	To first decimal place.
Percentage of B. coli tests.	To nearest whole number.
Chlorine.	To first decimal place.
Hardness.	To nearest whole number.
Alkalinity.	To nearest whole number.
Carbon dioxide.	To nearest whole number.
Iron.	To second decimal place.
Oxygen consumed.	To first decimal place.
Manganese.	To second decimal place.

In general, averages of the above results should be carried out one decimal place beyond those mentioned, but in case the average is that of only a few items, this additional place is not necessary or desirable.

B. Coli Tests. In recording the results of tests for B. coli, it is recommended that when possible the words "Positive" and "Negative" be used, or their abbreviations, "Pos." or "Neg." If signs are used instead of words, it is suggested that the mathematical symbols plus (+) and minus (−) be used to indicate positive and negative results, and that when no test is made, the space shall be filled in with dots (. . . .) and not a dash, which latter might be taken for a minus sign, or a zero, which might be taken for "no test."

The B. coli index is the approximate number of B. coli per c.c., as determined from qualitative tests made upon different quantities of water. For any individual sample, it may be taken as the reciprocal of the smallest volume of water used in the test which gave a positive result. Thus if a sample gave a positive test

with 0.1 c.c. and a negative test with 1.0 cc. and 10 c.c., the B. coli index would be 1 ÷ 0.1 = 10. The B. coli index for a single sample is not very accurate. The index becomes more and more precise as the square root of the number of tests becomes larger.

The B. coli index may be computed from a series of results as follows:

Write down the percentages of positive tests for the given quantities examined, expressed as decimals of 100.

Take the differences between these percentages.

Multiply each of these differences by the reciprocal of the quantity corresponding to the larger of the two percentages from which such difference was taken.

The sum of these products will be the B. coli index.

For example, for the year April, 1912, to March, 1913, the records of the Metropolitan Water Board of London, England, show results as given in the first two columns below.

Quantity of Water Examined.	Per Cent. of Positive Tests.	Expressed as Decimals of 100.	Differences.	Reciprocals of Quantities.	Product.
100 c.c.	13.8	0.1380	.1090	.01	.00109
10 c.c.	2.9	0.0290	.0260	.1	.00260
1 c.c.	0.3	0.0030	.0026	1.0	.00260
0.1 c.c.	0.04	0.0004	.0003	10.0	.00300
0.01 c.c.	0.01	0.0001	.0001	100.0	.01000
0.001 c.c.	*	-		Index =	.01929

* No test, but assumed to be zero.

In the above example the B. coli index may be taken as 0.019, which would be equivalent to 19 B. coli per liter of water.

Efficiency of Operation. It will be noticed that no provision has been made in these tables for recording the percentage removal of bacteria, a method that has been much used in the past. Although this method has certain advantages, it is so susceptible to misuse that the committee recommends that it be omitted from official reports of filter operation.

Reasons why the "Percentage Removal" Method is Unsatisfactory. The common method of judging the efficiency of a water filtration plant by means of the percentage removal of bacteria is unsatisfactory for several reasons.

ERRATA.

Report of Committee on Statistics of Water Purification Plants.

Journal N. E. W. W. Association, Vol. 28.

On page 227, the next to last word should be "negative" and not "positive," and on page 228 the word "negative" should be changed to "positive," so that the sentence beginning at the bottom of page 227 should read:

Thus if a sample gave a negative test with 0.1 cc. and a positive test with 1.0 cc. and 10 cc., the B. coli index would be $1 \div 0.1 = 10$.

with 0.1 c.c. and a negative test with 1.0 cc. and 10 c.c., the B. coli index would be $1 \div 0.1 = 10$. The B. coli index for a single sample is not very accurate. The index becomes more and more precise as the square root of the number of tests becomes larger.

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Reasons why the "Percentage Removal" Method is Unsatisfactory. The common method of judging the efficiency of a water filtration plant by means of the percentage removal of bacteria is unsatisfactory for several reasons.

(1) The bacteria found in the effluent are not all derived from the raw water. A certain and varying number of them represent growths in the lower part of the filter. The bacteria from this source do not vary in number with the number of bacteria in the raw water, but with the rate of filtration, with disturbances occasioned by the collection of air within the filter, and with other factors of operation.

(2) It requires a certain time for the water to pass from the point where the raw water sample is taken to the point where the filtered-water sample is taken. Sometimes this amounts to several hours, and in the case of a water which changes rapidly in quality and character it is necessary to make an allowance for this time if a correct comparison is to be obtained. As a matter of convenience it is common to collect samples of the raw and filtered water at about the same time. Hence there may be an error due to this difference in phase. Whether or not this is of importance depends upon the uniformity in the character of the raw water.

(3) The percentage removal is to a certain extent a function of the number of bacteria in the raw water. It is a well-known fact that the percentage removal of bacteria is relatively high when the raw water contains large numbers of bacteria and relatively low when the raw water contains few bacteria. One reason for this is because the bacteria which develop within the filter are a smaller proportion of the total number of bacteria in the effluent when the number of bacteria passing through the filter is large.

(4) The percentage removed does not necessarily vary with the number of bacteria left in the filtered water. The following is an example:

Day.	Numbers of Bacteria.		Percentage Removed.
	Raw Water.	Filter Effluent.	
1st	50	3	90.4
2d	1 000	10	99.0
3d	600	20	96.6
Average	555	11	

It will be noted that on the day when the number of bacteria in the effluent was lowest, the efficiency as shown by the percentage removal was also lowest.

(5) The infectiousness of a water does not necessarily vary with the number of bacteria in the water, but in most waters there will doubtless be some connection between the two. A water polluted with surface wash would doubtless increase in infectiousness, and the numbers of bacteria would increase with increased stream flow. On the other hand, a water regularly polluted with sewage, other things being equal, would increase in infectiousness as stream flow decreased, that is, as dilution became less, while the numbers of bacteria under these conditions might decrease. Hence, there seems to be no very definite relation between the infectiousness of a filtered water and the percentage removed of bacteria by a purification plant, which percentage varies according to the numbers of bacteria in the raw water.

(6) If any comparison is to be made between the numbers of bacteria in the raw and filtered waters it would be better to use the "percentage of bacteria remaining," partly because the numbers themselves are smaller and easier to handle, and partly because the figures show to better advantage the variations in the operation of the filter; for example, when two filters, with the same raw water, are operating so as to produce 98 and 99 per cent. "removals" of bacteria respectively, the numbers of bacteria remaining in the effluent of the first will be twice as many as in the effluent of the second. Again, comparing one filter with an efficiency of 99 per cent. with another filter with an efficiency of 99.9 per cent., both operating with the same raw water, the difference at first sight seems small, yet the effluent of the first of these filters contains ten times as many bacteria as the effluent of the second. Hence, the method of stating efficiency of a filter plant in terms of "bacterial removal" may be misleading.

(7) A single figure showing the percentage removal of bacteria during a certain time — as, for example, a month — gives no idea of the regularity of operation of the filter during this period. For example, in the illustration above mentioned the percentage of bacteria remaining in the effluent varied on different days from 1.0 per cent. to 9.6 per cent. of the number of bacteria in the raw

water, while the average of the per cents. remaining was 3.7 per cent. and the median 3.4 per cent.

(8) A common fault of filter specifications is the provision that the plant shall show a certain percentage removal of bacteria when the numbers of bacteria in the raw water are below a certain limit. This specification is inadequate. A good water-purification plant is one which produces a satisfactory effluent every day of the year and every hour of the day; and, if efficiency can be expressed on a percentage basis, it should be indicated by the percentage of the time during which the plant produced a good effluent, rather than by the percentage comparison of bacteria in influent and effluent respectively.

TABLE 1.—CHEMICAL AND MICROSCOPICAL CHARACTER OF (RAW) WATER.
For the Year ——.
(Parts per 1 000 000.)

Month.	Chlorine	Total Hardness.	Permanent Hardness.	Alkalinity.			Free CO_2		Dissolved Oxygen.	Iron.	Suspended Matter.	Oxygen Consumed.	Micro-Organisms.	Remarks.
				Av.	Max.	Min.	Av.	Max.					Std. Units per c.c.*	
Jan. ↓ Dec.														
Average														

* Use standard units; if numbers are used, so state.
[Raw] Water to be designated by name of source, e. g., "Hudson River," "Wells," "Lake George."

TABLE 2.—TURBIDITY AND COLOR OF ( ) WATER.
For the Year ——.
(Parts per 1 000 000.)

Month.	No. of Test Days.	Mean Turbidity.	Turbidity. Variations: No. of Test Days.							No. of Test Days.	Mean Color.	Color. Variations: No. of Test Days.				
			0–10.	11–25.	26–50.	51–100.	101–250.	251–500	Above 500.			0–10.	11–25.	21–50.	51–100.	Above 100.
Jan. ↓ Dec.																
Total																
Average																
% Time																

TABLE 3.—BACTERIA IN (   ) WATER.
For the Year ——.

Month.	No. of Bacteria on Gelatine at 20 Degrees C.									Bacillus Coli.											
				Variations in Numbers: No. of Test Days.							0.01 c.c. Tests.			0.1 c.c. Tests.			1.0 c.c. Tests.			B. Coli Index.
	No. of Test Days.	Mean per c.c.	Median per c.c.	0–100.	100–300.	300–1 000.	100–10 000.	10 000–100 000.	Above 100 000.	No. of Test Days.	Total No.	No. +	Per cent. +	Total No.	No. +	Per cent. +	Total No.	No. +	Per cent. +	Number per c.c.
Jan. ↓ Dec.																				
Total																				
Average																				
Per cent. time																				

TABLE 4.—CHEMICAL CHARACTER OF WATER DELIVERED TO MAINS.
For the Year ——.
(Parts per 1 000 000.)

Month	Chlorine.	Total Hardness.	Permanent Hardness.	Alkalinity.		Free CO_2.		Iron.	Oxygen Consumed
				Average.	Minimum.	Average.	Maximum.		
Jan. ↓ Dec.									
Average									

TABLE 5.—TURBIDITY AND COLOR OF WATER DELIVERED TO MAINS.
For the Year ——.
(Parts per 1 000 000.)

Month.	Turbidity.						Color.				
	No. of Test Days.	Mean Turbidity.	Variation in Turbidity: Number of Test Days.				No. of Test Days.	Mean Color.	Variations in Color: Number of Test Days.		
			0.	1–5.	6–10.	Above 10.			0–5.	6–10.	Above 10.
Jan. ↓ Dec.											
Total											
Average.											
Per cent. time											

TABLE 6.—NUMBERS OF BACTERIA IN WATER DELIVERED TO MAINS.
For the Year ——.

Month.	On Gelatine at 20 Degrees C.									On Agar at 37.5 Degrees C.							
	No. of Test Days.	Mean per c.c.	Median per c.c.	Variations in Numbers: No. of Test Days.						No. of Test Days.	Mean per c.c.	Median per c.c.	Range of Counts.				
				0–10.	11–25.	26–50.	51–100.	101–250.	Above 250.				0–10.	11–25.	36–50.	51–100.	Above 100.
Jan. ↓ Dec.																	
Total																	
Average																	
Per cent. time																	

TABLE 7. — NUMBERS OF BACILLI COLI IN WATER DELIVERED TO MAINS.

For the Year ——.

Month.	Bacillus Coli.							B. Coli Index.	Remarks.
	No. of Test Days.	One c.c. Tests.			Ten c.c. Tests.			Number per c.c.	
		Total No.	No. +	Per cent. +	Total No.	No. +	Per cent. +		
Jan. ↓ Dec.									
Total									
Average									
Per cent. time									

DISCUSSION.

Mr. Edwin C. Brooks. Mr. Whipple has given us an excellent test for finding dirt or algæ in a sample of water. The Cambridge water supply pipes have been in years past galvanized iron pipes, and we all know that they fur up very rapidly, and that the interior becomes very rough. The question arises whether, unless a sufficient amount of water is drawn through the pipe to thoroughly wash it out, you will get a fair sample of the water in the main.

Mr. Robert S. Weston. I have collected a number of cotton sediment records from different parts of New England. There is a series taken since the 16th of August from the Metropolitan water-works tap at 14 Beacon Street, and you see there is a great variation in cleanness. On the 25th of August the water was quite dark in color, that is, the sediment was quite dark, but in a majority of cases the water is fairly clean. Also there are a number of tests made with Brookline water. The Brookline water, as you know, contains iron. Sometimes the iron settles out in the mains, and sometimes the iron rust becomes evident at the taps. There are also tests of samples from the experimental filter which Mr. Forbes is running, showing the sediment in the raw water and in the water from the settling basin and the absence of sediment from the filtered water. There are some samples from Belfast, Me., and other places.

Perhaps Professor Whipple didn't say that the committee hopes to be able to continue its work and to take up among other things the question of the effect of filter operations upon the vital statistics. It has been stated by a great many people that water filters, especially mechanical filters, are efficient, and by some others that they are not, and it seems a good time for the committee to get some facts as to the real hygienic value of these devices, with the hope of advancing the subject beyond the controversial stage.

The financial statistics of water purification plants are also in a rather chaotic condition, and the committee hopes to be able to make some contribution along this line. For instance, the cost of operation without depreciation and without interest is

often compared with the cost of operation with these fixed charges included, and the cost of operation very often includes such items as "care of grounds," etc.

The committee also hopes to acquire copies of the records from the various water purification plants, and desires the operators of such plants to coöperate with it in getting such operation data recorded on the standard forms. A few plants are furnishing very good records, but no two records are on the same basis.

THE NEW WATER PURIFICATION PLANT AT MIRAFLORES, CANAL ZONE.

BY GEORGE M. WELLS, DIVISION ENGINEER.

[*Read September 10, 1914.*]

As an introduction to a paper descriptive of the New Water Purification Plant, now in course of construction by the United States Government near the Miraflores locks, it has occurred to the writer that a brief outline of the conditions from which resulted the decision to adopt an entirely new project for the water supply for the southern end of the Panama Canal might prove of interest to the members of the New England Water Works Association.

The water supply for all points in the canal south of the Culebra Cut, including the towns of Paraiso, Pedro Miguel, Corozal, Ancon, Balboa, and the city of Panama, was obtained, prior to October, 1913, in part from the Rio Grande reservoir by gravity, and in part from the Cocoli lake by pumping.

The Rio Grande reservoir is located on a river of the same name, about eleven miles distant from the city of Panama, and along the old line of the Pánama Railroad on the west side of the canal. A 16-in. cast-iron main laid in 1905 and a 20-in. cast-iron main laid in 1912 carried the water from the reservoir through the first four towns above mentioned to Panama City and Balboa. At the west side and north end of the Pedro Miguel locks these mains were combined into a single 24-in. main, which was laid in the masonry floor and side walls and extended to the east side, where the 16-in. and 20-in. mains continued along the line of the Panama Railroad for the remainder of their length.

Early in 1910 the consumption of water had risen to over 3 500 000 gal. per day, and it became necessary to supplement this amount by pumping from the Cocoli River, as the Rio Grande reservoir could not be relied upon to furnish much in excess of that amount during months of minimum rainfall. Temporary

electric-driven pumps were installed on the Cocoli, a river lying on the west side of the canal, opposite Miraflores. Temporary pipe lines were laid from these pumps across the Miraflores locks and connected in to the 16-in. and 20-in. mains from Rio Grande.

The watershed of the Rio Grande reservoir is uninhabited, and is rigidly kept free from all trespassing. This was also more or less true of the Cocoli watershed, and the water from these sources was practically above suspicion as far as pollution from human beings was concerned. The water, however, was objectionable from the standpoint of iron content, color, and odor, and a certain amount of purification was obtained by pumping that portion of the supply reaching Panama City through pressure filters, Continental Jewell type, without sedimentation.

By 1913 the consumption had risen to 7 500 000 gal. per day, thus taxing both the Rio Grande and Cocoli supply to the utmost. The approaching completion of the Miraflores locks and the creation of the Miraflores lake resulted in the flooding of the lower part of the Cocoli valley, and consequently eliminated this part of the supply, necessitating the moving of the pumps to the east side of the canal, where they were installed for pumping water into the 16-in. and 20-in. mains from the newly created lake, as a supplementary supply.

By reason of the territory flooded and also by reason of the sewage emptying into the lake from the town of Pedro Miguel, located at the northern end, the water is more or less polluted. A hypochlorite dosing plant was therefore installed, and from 8 to 11 lb. of bleach per million gallons is being applied to all water passing south of Pedro Miguel.

The more or less inadequate and unsatisfactory water supply was the subject of considerable study as far back as the early part of 1912, and in March, 1913, a committee, of which the writer was a member, was convened to report on and recommend an entirely new project for the permanent water supply for the southern end of the Panama Canal. After several months of study, during which time five different projects were worked up, including estimates of costs, the project now under construction was submitted by the writer and approved by the chairman and chief engineer.

This project involved the abandonment of the Rio Grande supply and the taking of all water from an arm of the Miraflores lake lying east of the Panama Railroad and just north of the railroad tunnel; the construction of a raw-water pumping station at the edge of the lake; the purification of the water by aëration, sedimentation, filtration, and hypochlorite treatment; the laying of a new 30-in. cast-iron main from Miraflores to Ancon; the construction of a booster pumping station at Ancon; the enlargement of the existing 1 000 000-gal. reservoir on the side of Ancon Hill to 2 500 000 gal. capacity; the laying of a new 16-in. cast-iron main from the booster station to this reservoir, and the laying of the necessary new 20-in. and 16-in. lines between this pump station and the city of Panama, the canal terminals, and permanent towns.

The results of the various studies and the many reasons leading to the adoption of the project as outlined will not be taken up in this paper. Suffice it to state, however, that the necessity for meeting the increasing water demands; the requirement that existing pumping stations and pipe lines should be moved or changed as the canal construction demanded without interruption to the supply; that any new plant proposed should provide for either low or high-pressure service through a single distributing system, extending from practically sea level to nearly 200 ft. above; the necessity of using Miraflores-lake water, which is, and always will be, more or less polluted; the requirement that the water furnished should be above suspicion and free from odors, taste, color, iron, and all organic matter; and finally the natural topographical difficulties to be overcome, — all combined to present a most interesting problem, not only from the standpoint of design but from the standpoint of first cost and economy of operation as well.

The purification plant is located at the extreme westerly end and on the crest of the ridge, which extends with precipitous sides from the high hills lying east of the Panama Railroad tunnel at Miraflores to the spillway at the north end of the locks. This places the filter building end of the plant almost immediately above the east abutment of the spillway. The finished ground elevation around the buildings has been fixed at 116 ft. above

sea level, or approximately 61 ft. above the normal level of the water in Miraflores lake.

The plant as designed provides for a nominal maximum capacity at a 125 000 000-gal. per acre rate of 12 000 000 gal. per day, and an extrême maximum capacity at this rate of 15 000 000 gal. per day, exclusive of wash water and with one filter out of service.

The raw water will be delivered to the aëration basin through a 30-in. cast-iron main from the so-called raw-water pumping station located, as stated, on the arm of the Miraflores lake lying east of the Panama Railroad. Falling to the floor of the aëration basin the water will pass into the basement of the head house over shallow weirs. At these weirs it will receive a dose of aluminum sulphate, and will then pass through a series of mixing chambers into the sedimentation basin. This basin, which will be the continuous type, will provide from five to eight hours of sedimentation. Passing out of the sedimentation basin the water will flow to 14 filters through two 30-in. distributing pipes, and from the filters will pass through specially designed controllers through the floor of the pipe gallery directly into a clear water basin extending over the entire area beneath the filter beds. From this basin the water will flow through a 30-in. main to an injection and mixing chamber located approximately 150 ft. distant from and about 25 ft. lower than the floor of the clear water basin. In this chamber will be applied a dose of hypochlorite of lime, and after passing through a series of baffles the water will finally enter the cast-iron mains leading to the Ancon booster pumping station located approximately five miles to the south.

Water for washing filters, for service around the plant, and for supplying the town of Pedro Miguel, located about two miles to the north, will be furnished by pumps placed in a second station, known as United States Pumping Station No. 2, and located near the injection chamber. This station will deliver the water from the mains to a 300 000 gal. capacity concrete tank located on the ridge to the east of the main plant and at an elevation of approximately 200. The wash water will be delivered from this tank to the filters through a 20-in. cast-iron main, and the general service water will be carried to the plant through a separate 4-in. cast-iron line.

For sake of clearness and convenience, a detailed description of the different units of the plant will be taken up in the following order: Aëration Basin; Head House and Mixing Chambers; Sedimentation Basin; Filter Building; Injection Chamber; Effluent Controllers; Alum and Hypochlorite Mixing Apparatus, and Hypochlorite Dosing Apparatus.

AËRATION BASIN.

All ground waters on the Isthmus of Panama, at least all within the Canal Zone, when allowed to stand in reservoirs or pipes, at times give off objectionable odors when discharged. These odors result from the hydrogen sulphide gas given off by the large quantities of decomposing vegetable matter present in the raw water. Aside from being acutely disagreeable to the sense of smell, this gas attacks all paints in the immediate vicinity having lead or zinc bases, and also discolors metals. The odor given off by the Gatun Lake water as it flows over the spillway at times reaches such volume and strength as to be plainly noticeable down the wind for a distance of nearly two miles. It is obvious that in the treatment of water of such character more or less elaborate aëration seems warranted.

The iron content in the water of the Miraflores lake generally runs from .8 to 2.5 parts per million. This iron is in solution, and experiments conducted, using compressed air at low pressure and considerable volume, indicated that aëration might be expected to prove of valuable assistance as a preliminary treatment to the application of sulphate of aluminum. The changing of the iron from the ferrous to the ferric state during aëration and its partial elimination by precipitation in the aëration basin seemed to result — at least in the case of the water passing the Gatun purification plant at Agua Clara — in an appreciable reduction in the amount of aluminum sulphate required to remove the color. This becomes a vital point in waters of low alkalinity and high color, and the writer in designing the new plant for Colon and Cristobal attempted a more or less elaborate aëration system. This plant is just going into operation, and definite data on results are therefore not available at this time.

For similar reasons, although the iron content in the Miraflores water is a little lower than in the Colon water, the aëration basin becomes an important part of the Miraflores plant.

This basin, as designed, will be a reinforced concrete structure, rectangular in plan, 86 ft. wide by 125 ft. long, inside wall dimensions. The floor will be flat, resting throughout its area directly on clay foundation, and will have a thickness of approximately 6 in. The side walls, 6 in. in thickness, will extend 6 ft. above the floor, and are merely to prevent the waste of water that would result from the striking of the spray on the concrete floor after falling from a height of 15 to 20 ft. The elevation of the floor has been fixed at 126.

The 30-in. main from the raw-water station will extend the full length of the north side of the basin and will be outside the wall, distant therefrom about 4.5 ft., and below the floor level approximately 2.5 ft. From the top of this 30-in. pipe will be taken off seven 12-in. diameter pipes spaced at intervals of 16 ft. Each of these pipes will lead horizontally through the side wall on to the floor of the basin, and at a point 15 ft. inside will split into two 8-in. pipes, which will form a loop extending across the basin. The pipes when assembled will present the appearance of a grid of fourteen 8-in. pipes, with each pair cross-connected at the southerly side of the basin and fed by a single 12-in. line at the opposite side.

At intervals of 8 ft. on the 8-in. pipe will be located 4-in. outlets extending vertically upward. These outlets will be staggered in such a way as to cause them to be located in triangular plan. To each of these outlets will be located the bronze aëration nozzle. There will thus be a total of 105 nozzles.

The nozzle adopted will consist of a special flanged outlet within which will fit a bronze truncated cone having a face angle of 20° inclination from the vertical. The diameter of the outlet will be $3\frac{3}{8}$ in., but the maximum opening between the lip of the outlet and the face of the cone will not exceed $\frac{3}{16}$ in. measured perpendicular to the cone for maximum required discharge. The cone will be held in place by an adjustable bronze bolt extending into a cross rib located just above the plane of the flanges connecting the nozzle to the 4-in. outlet from the 8-in. feed pipe.

The design of these nozzles was determined upon after experiments with nozzles of different types and by full sized tests had shown the character, volume, and shape of the spray delivered under varying heads.

Under operating conditions it is expected that the water from these nozzles will be thrown from 15 to 20 ft. into the air, and the tests showed that the water was broken from a thin sheet into coarse drops about two thirds of the distance up, changing to spray at the top of the rise and falling as such to the basin floor.

Each nozzle at full pressure will deliver approximately 200 000 gal. per day, but the opening is so designed that when delivering 50 per cent. of this amount at a low pressure, satisfactory breaking up of the water may be expected.

Outside the basin wall, in each 12-in. feed pipe, will be located two valves, one hand-operated and one hydraulically operated. The piping from the latter valves will lead to controllers located in a float box in the head house. This box will be connected by a 12-in. pipe to the receiving chamber at the entrance to the filter building, and the water level rising or falling in this box simultaneously with the level in the receiving chamber will actuate floats carrying stems to small piston valves, which will open or close the hydraulic valves at the aëration basin, cutting out or in the various banks of nozzles according as the throwing in or out of filters increases or decreases the draft on the sedimentation basin. By this means the quantity of water admitted to the aëration basin will be automatically regulated to meet the more or less constantly varying outflow to the clear-water basin, resulting from throwing filters in and out of service.

The float controller for the hydraulic valves will consist of a bronze shell, within which will be placed a cylindrical piston attached by a vertical stem to a copper float resting on the surface of the water in the float box. The shell has been so designed that the feed water for operating the hydraulic cylinders on the valves will pass into it through ports, and, according to position of the piston, will flow to the top or bottom side of the valve cylinder, under pressure. The water from the opposite side of the hydraulic valve piston will escape through a waste port in the shell. In short, the controller is a simple adaptation of a cylinder and piston

valve for accomplishment through float movement of the same result obtained by the ordinary hand-operated four-way valve. The hand-operated 12-in. valves referred to are to be operated only at times when the occasion may arise to remove or repair the hydraulic valves.

The water will pass from the aëration basin to the mixing chambers in the head house over three weirs 12 in. deep by 15 ft. in length, which will be simple slots in the back wall of the head house. These weirs will have their crests at such an elevation that for maximum flow the depth of water on the floor of the aëration basin will not exceed 9 in.

HEAD HOUSE AND MIXING CHAMBERS.

The head house will be a reinforced concrete building, approximately 38.5 ft. wide by 92 ft. in length, and three stories in height. It will be located between the aëration basin and the sedimentation basin, and the lower portion of its side walls will form the east and west end walls of the sedimentation and aëration basins respectively.

The bottom story or basement will contain three separate mixing chambers, each 15 ft. in width and extending across the building from the aëration basin weir to the entrance weirs to the sedimentation basin. The layout of under drainage piping and valves for removing sludge will also be located on this floor. At the southern end of the building will be located the freight elevator, running from the basement to the third floor. On the basement floor and at this end of the building will also be located lavatories, shower baths, lockers for the colored employees, transformer room, and room for the elevator machinery and motors. At the opposite end of the building, the main entrance end, placed between the floor of the basement and the second floor, will be located the float box above described in connection with the aëration basin. This will appear depressed below the floor level on each side of the main entrance as one enters to the second floor.

The walls of the mixing chamber will rise to the level of the second floor, and here will be located the constant head float boxes and apparatus for measuring and applying the aluminum sulphate to the water as it passes into the mixing chambers from

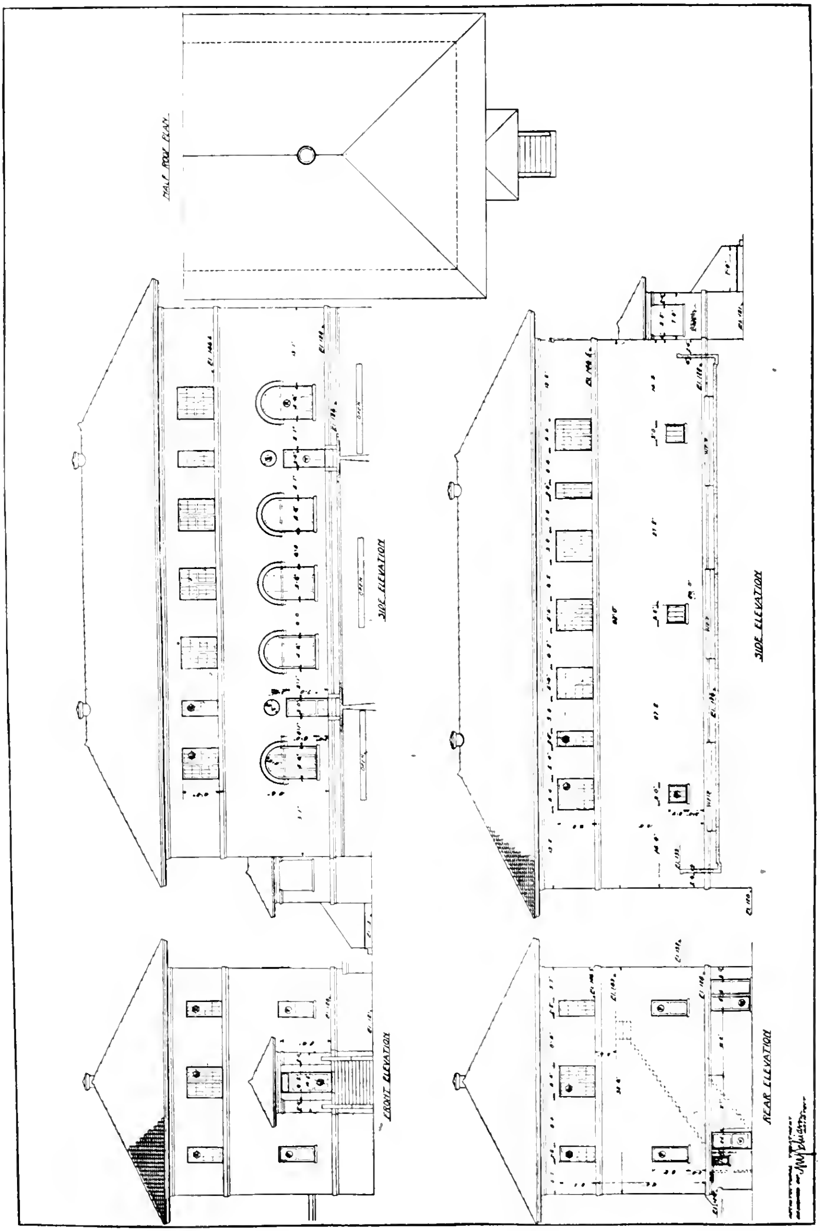

FIG. 1. ELEVATIONS OF HEAD HOUSE.

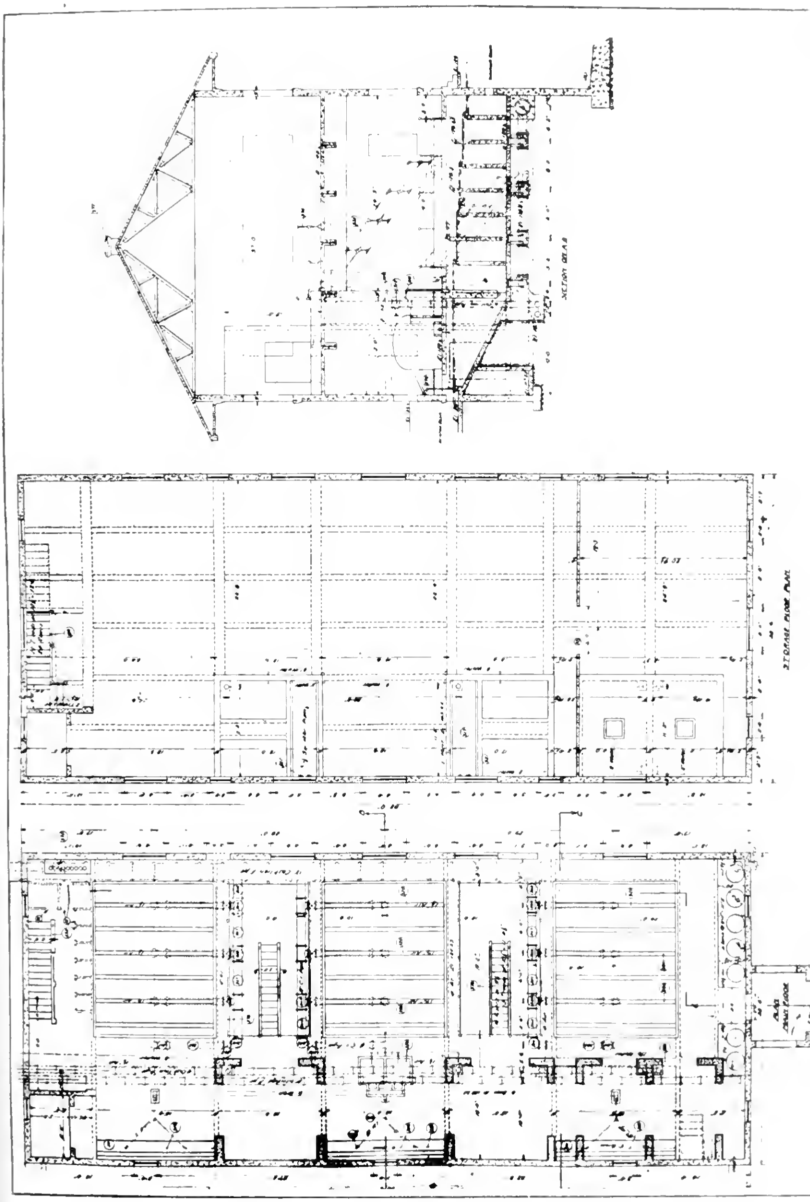

FIG. 2. SECTION AND PLAN OF HEAD HOUSE.

the aëration chamber. From this floor access will be had to the walks along the tops of the sedimentation basin walls, and here will also be located the slate operating table from which will be controlled the hydraulic valves for draining the sedimentation basin.

The third floor will carry two aluminum sulphate and two hypochlorite of lime solution tanks. The alum tanks will be 12 ft. square by 9 ft. in depth, with their walls reaching about 1.25 ft. above the floor level and 7.75 ft. below. The hypochlorite tanks will be 8 ft. by 12 ft. by 9 ft. deep, with walls also extending above and below floor level.

The hypochlorite room will be provided by running a concrete partition across the building about 21 ft. from the north end and just clear of the hypochlorite tanks. This will give floor space, including tops of tanks, of 21 ft. by 37 ft. The remainder of the floor, 37 ft. by 69 ft., will provide space for about nine months' alum storage. The alum and hypochlorite will be delivered to the south face of the building in wagons and lifted to the storage floor by an electric-driven platform elevator. Air-driven traveling triplex blocks, running on I-beams hung to the lower side of the roof trusses, will provide for ready and convenient handling of material from elevator to storage. Separate trolley blocks will run over the tops of alum tanks, for the easy placing of the aluminum sulphate on to the dissolving screens.

The mixing chambers will be concrete boxes approximately 37 ft. long by 15 ft. by 8 ft. deep. Each chamber will be divided transversely by 6-in. walls into eight compartments. One half of these walls will extend to within 6 in. of the bottom of the chamber forming submerged weirs, and the tops of the remainder of the walls will form over-fall weirs, with the elevation of each weir beginning at the aëration basin end $4\frac{1}{2}$ in. higher than the next succeeding one.

Extending along the edges of the submerged weirs will be placed $1\frac{1}{2}$-in. pipes having $\frac{1}{8}$-in. diameter holes spaced 6 in. centers, drilled in the lower half. Through these pipes compressed air at a pressure of about 5 lb. per sq. in. will be admitted into the chamber during operation.

The water entering the first compartment of the mixing chamber,

from the weir placed in the main wall, will pass under aluminum sulphate solution injection pipes and, receiving its proper dose of chemical, will flow vertically down and through the first submerged weir. In passing this weir the water will pass through jets of compressed air, and rising to the top of the second compartment will pass over the first over-fall weir to the third compartment. In this manner, the water will flow over and under successive weirs to the sedimentation basin. It is estimated that the water will be, under full operating conditions, five minutes in passing through these mixing chambers, and that this will provide ample time for thorough mixing and the complete formation of floc before reaching the first section of the sedimentation basin.

These mixing chambers are in no way connected with each other, and correspond with the three main divisions of the sedimentation basin. In the event of two thirds or all of the sedimentation basin being in operation, the entry weirs at the aëration basin, placed as they will be at the same elevation, will split the flow into two or three equal parts as the case may be. With the entire plant in operation, there will in effect be three mixing chambers and three sedimentation basins working simultaneously in parallel, each delivering its one third of the total to the filter building. This arrangement allows one or more divisions to be thrown out of service and cleaned, as desired, without interference with the operation of the remaining divisions. With the exception of a small area at one end of the mixing chambers, the water is visible to the operator throughout its course to the sedimentation basin, and the condition of the water as affected by the chemical may be under constant observation.

Eight in. and 10-in. cast-iron sludge pipes connect the bottom of each compartment with the main outfall sewer, and the valves controlling these lines will be located on the floor of the basement, reached either from the second floor by stairs or from the basement gallery running the full length of the building next to the aëration basin wall.

SEDIMENTATION BASIN.

The sedimentation basin will extend from the face of the head house wall to the east wall of the filter building. It will be of

reinforced concrete, rectangular in plan, with dimensions, center to center of outside walls, 125 ft. by 300 ft. The depth at the floor valleys will be 17.75 ft., and at the summits, 16.5 ft. Its capacity will be approximately 4 500 000 gal. The floor will be located about 7 ft. below the finished ground level and the walls will thus have 9.5 ft. of face above.

The basin will be divided longitudinally into three main divisions by pressure walls. Each of these divisions will be operated entirely separate from or in conjunction with either or both of the other divisions. They will be divided transversely into three compartments by two pressure walls. The first and second compartments will be divided into three sections by two light-baffle walls running across the compartment. These baffle walls will be solid for a distance of three feet up from the bottom, and above this they will be pierced with as large openings and as many as practicable, reaching to within 2.5 ft. of the top. The remaining height of wall will be solid. The third compartment next to the filter building will be divided into two sections by one baffle wall only, built in the same manner as described for the first and second compartments.

The floor of the first two compartments will slope 1 in 12 from each baffle and transverse pressure wall to center valleys running transversely across the basin. In each of these compartments there will thus be three valleys. In the third compartment the floor will slope 1 in 20 to two central valleys.

The under-drainage system will consist of 20-in. cast-iron leadite jointed pipe, laid in solid concrete about two feet below the floor at the valleys. One 20-in. pipe line will be placed at each valley and will extend through to a main discharge sludge culvert, running parallel to the outside wall on the south side of the basin and located about six feet distant from the wall face.

In each section of a compartment will be located two 16-in. diameter outlets leading into the 20-in. under drain. These outlets will be located at about the quarter points in the valleys.

The sludge culvert will be built of reinforced concrete, and will be 3 ft. by 3.75 ft. in cross section, and the 20-in. under drains will have their outlets in the side walls of this culvert. Near the filter building end of the basin the culvert will end in a 24-in. cast-

iron pipe, laid in concrete, extending down the hill to the south to elevation about 100, and there reducing to 20-in. diameter, it will follow the hill around the westerly end of the filter building until it passes the abutment of the spillway, and then drop directly to lake level at elevation 55. With the elevation of the water in the sedimentation basin at 125 and the outlet of the 20-in. discharge pipe at 55, it is expected that the compartments will be largely self-cleaning.

Each 20-in. under drain will be controlled by a 20-in. hydraulically operated gate valve located in a covered gallery just above and between the discharge culvert and the outside of the southerly wall. On the wall of this gallery will be carried the control piping for the valves. This piping will end in a slate operating table, of the filter table type, that will be located on the second floor of the head house. The emptying of any compartment or division will therefore be controlled from one point in the head house where the operator will have a clear view over the entire basin.

The treated water as it falls from the last weir in the mixing chamber will pass into the first compartment through one port or submerged weir, 1.5 ft. wide by 15 ft. long, located in the wall 3.5 ft. below the normal water level. The path of the water will then be through the large submerged ports in the baffle wall to the pressure wall separating the first and second compartments. This wall will be pierced with five ports, placed about 3.5 ft. below water level and extending throughout its length. Each port will be 1.5 ft. wide by 6 ft. long. In front of these ports will be placed a thin concrete wall supported on a floor or shelf extending out from the main wall at a point just below the bottom of the ports. This wall will extend to within a foot of the surface of the water and thus form a skimming weir extending the entire width of the compartment. The water will thus pass over this weir and then down through the ports into the second compartment. This arrangement of ports and skimming weir is repeated in the second pressure wall, and the water finally reaches the receiving box, located between the end wall of the basin and the wall of the filter building, by passing over a third weir of somewhat different construction from the skimming weirs.

In the tops of the two main pressure walls extending longi-

tudinally through the basin, separating it into the three divisions, and at the head house end, will be placed weirs with flashboards for cross filling purposes.

For the purpose of illustrating the operation of these weirs, let us assume two adjacent divisions of the basin in operation, together with the two corresponding mixing chambers. The flashboard on the weir at the aëration basin, leading into the third mixing chamber, is down, and this chamber, together with the third division of the sedimentation basin, is empty and cleaned, ready for filling with treated water preparatory to throwing into service. Let us further assume that the filters are running at full capacity of 15 000 000 gal. per day.

The flashboards on the cross filling weirs are first lifted, thus allowing an overflow from the two operating divisions into the empty division. The flashboard on the third weir at the aëration basin is also lifted. The level of the water in the receiving box at the filter building drops, due to the drop of level over that portion of the basin in operation. This lowers the level of the water in the controller box located in the head house, as referred to in the description of the aëration basin, and this causes one or more additional hydraulic valves on the inlet pipes to the aëration nozzles to open and admit all the water that the pumps in the raw water station will furnish. The weirs at the aëration basin will split the incoming water into three equal parts, and two thirds will flow to the divisions of the basin feeding the filters and the third part will flow to the empty division. In passing through the third mixing chamber it will receive its dose of aluminum sulphate as in regular operation. This condition will continue without disturbances to the filter operation until the third division fills to the cross filling weir crests. As the general level commences to rise, the water level in the controller box will also rise and gradually shut down the valves on the pipes leading to the aëration nozzles until equilibrium between incoming and outgoing water is established.

The sedimentation basin has been divided as described above into compartments for reasons of water economy. The behavior of the basin at the Gatun-Agua Clara plant shows that about 80 per cent. of the sludge may be expected to lodge in the first com-

partment; that 15 per cent. will remain in the second, and that the remaining 5 per cent. will reach the third compartment. It has also been found necessary to clean basins on the isthmus when the sludge reaches a depth of three or four feet, and this may be expected every seven or eight days. With the basin divided into divisions and compartments as described, it is expected that once a week the first compartment may be cleaned without disturbing the other two compartments, except to throw them out of service temporarily; that once in two weeks the second and third compartment may be cleaned, and once every three weeks or a month the entire division may be cleaned. Such an arrangement, if satisfactory, will lead to a large saving in water over any arrangement that requires the entire division to be drained when it becomes necessary to clean, and when such necessity is brought about by the fouling of only a small portion of the division concerned; $2\frac{1}{2}$-in. wash-water lines for use in cleaning the basin walls and floor will be laid in the concrete walls, and $2\frac{1}{2}$-in. fire-hose outlets will be placed near the tops of the walls at the center of each compartment.

The walls have been designed as cantilevers, and they run from 2 ft. 7 in. thickness at the bottom to 6 in. thickness at the top. On the top of the walls will be laid 2-ft. wide concrete sidewalks, so that ready access can be had to any part of the basin. Night illumination will be provided by placing 14 concrete lamp posts, mounted with 250-watt Tungsten lamps covered with 13-in. diameter opalescent globes, at different points on the tops of the walls.

A basin having such a marked difference between length and breadth dimension as the one at Miraflores may seem to many to suggest much greater expense in first cost. Topographical restrictions compelled the shape of this basin, and any increase in width would have resulted in pile foundations due to the ridge being too narrow to carry a greater width than 125 ft., and the increased cost due to greater length of perimeter would be more than offset by expensive foundation work for a wider basin.

FILTER BUILDING.

The general ground plan of the filter building is rectangular in shape, and will cover a space of approximately 62 ft. wide by

175 ft. in length. It will be divided into what may be considered two separate buildings. That portion of the structure lying immediately adjacent to the western end of the sedimentation basin will have a ground plan of 28.75 ft. in width by 51.5 ft. in length, and will be three stories in height. The second portion, containing the filters, pipe galleries, and clear-water basin, will extend at right angles to the above building for a distance of approximately 148 ft., and with a width of 62 ft. The first portion of the entire structure as described above will be known as the office, laboratory, and quarters building, in distinction from that portion containing the filters only.

There will be a total of fourteen filters, placed in two rows of seven each, with the operating floor and pipe gallery running between them. Each filter will be 19.75 ft. by 21.5 ft. in plan by 11 ft. in depth from the top of the walls to strainer pipe floor. At a rate of 125 000 000 gal. per acre per twenty-four hours, each filter unit will have a capacity of 1 220 000 gal. per day. The width of the pipe gallery and operating floor between filter walls will be 15 ft.

The filters will be entirely under cover, and the outer walls will be run up a distance of about 8 ft. to form the building side walls and support the trusses carrying the roof. The steel trusses will have a clear span from wall to wall of 61 ft., and the lower chords will be curved to a radius of 100 ft. There will be 6 trusses spaced 20.75 ft. center to center. The side walls and wall at the opposite end from the laboratory office and quarters building will be pierced with large circular topped windows.

The operating floor will be placed at a level 2.5 ft. below the top of the filter walls, and access will be had to it from the main floor of the office building by a broad flight of five steps. This main floor will be at the elevation of the tops of the filter walls, and will be separated from the filter portion of the building by a concrete wall in which will be placed large circular arched openings throughout its length. An unobstructed and elevated view will thus be available over both banks of filters. On this main floor, to which the principal entrance will lead, will be located the office and the laboratory. The laboratory will be partitioned off into a room 20 ft. by 21 ft., and will have such openings as will permit a free view through the outer wall arches over the filters.

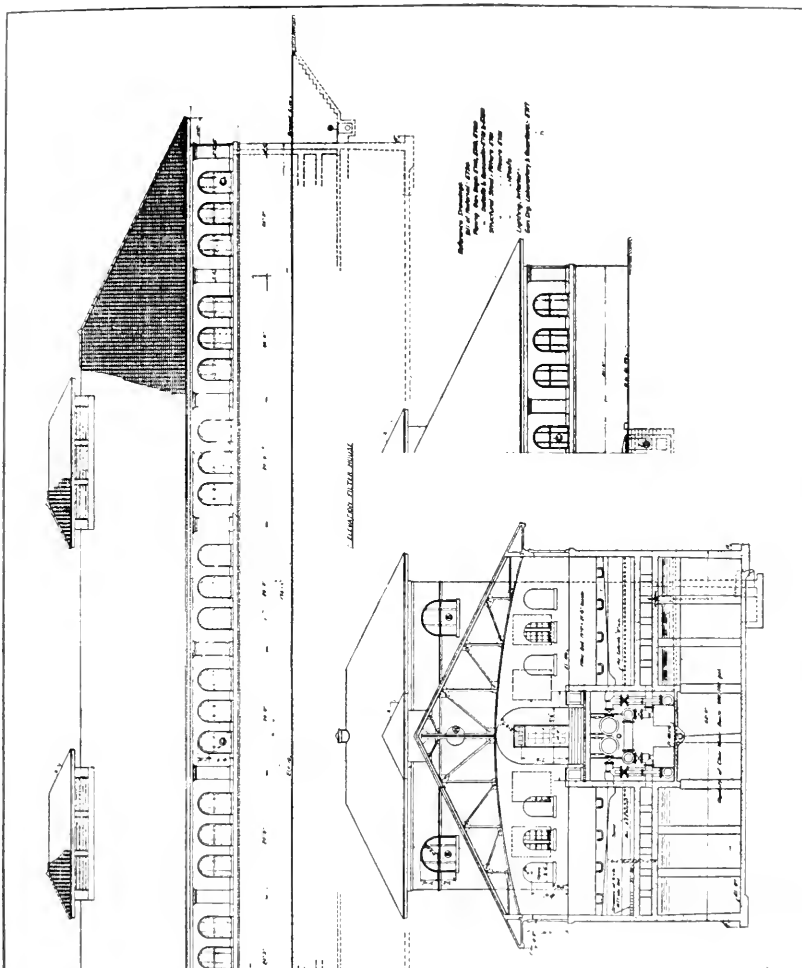

FIG. 3. FILTER BUILDING. EAST ELEVATION AND SECTION LOOKING SOUTH.

The third floor of the office, laboratory, and quarters section will contain three bedrooms, lavatories, and shower baths for the accommodation of chemists who will be in charge of the operation of the plant. Access to this floor will be had by concrete stairs off the main floor below.

The basement or first story will provide room for a compressed air receiver, transformers, storage and small repair benches, and will open directly into the pipe gallery between the filters.

A clear-water basin, having a depth of 12 ft. and a capacity of approximately 900 000 gal., will extend over the entire area below filters and pipe gallery floor.

In the design of the filter unit the usual under-drainage system of collector pipes has been abandoned and the false bottom or pressure-chamber plan adopted. The idea of the false bottom was first suggested to the writer by Mr. J. N. Chester, of Pittsburgh, but before the decision to adopt this system was made, more or less extensive experiments were undertaken to ascertain the most suitable type of strainer system; the relation between area of bed and total area of strainer openings; the pressure required in the pressure chamber for varying rates of wash from 5 gal. to 20 gal. per minute per sq. ft. of filtering area; the most suitable depth of gravel bed; the possibilities of having a mixing in the event of sudden admission of large quantities of wash water; the resulting uniformity of agitation over the bed; the most suitable arrangement of wash troughs, and the shapes of the trough edges acting as weirs.

A fully equipped filter 5 ft. square was built with a false bottom having an 18-in. space between it and the filter bottom proper. This filter was operated with certain depths of gravel and sand and different arrangements of troughs. Space will not be taken to discuss the results of the experiments with this small filter, but it may be stated that the design of the filters for the Miraflores plant as described herein is based as far as possible on the results obtained from them.

Each filter, as stated above, will be 19.75 ft. by 21.6 ft. by 11 ft. inside dimensions. The walls and bottom will be 12 in. thick, of reinforced concrete. The pressure chamber will extend over the entire area below the floor, and will be 2 ft. in depth to the

pressure floor. This floor will also be of reinforced concrete and 14 in. in thickness.

The filter has been designed for a normal washing rate of 15 gal. per sq. ft. of filtering area, and the pressure chamber has been designed to withstand a maximum pressure of 28 lb. per sq. in. The presence of a clear-water basin beneath the filters complicated the design to a certain extent in view of the necessity of taking care of the great vertical loads as well as the bursting pressure that will result from the above unit pressure. This, however, has been worked out satisfactorily on the drafting table and a full-sized test of a section of the pressure chamber will shortly be made to determine the most advisable manner in which to make the construction joints and also to learn what leakage may be expected under actual operating conditions. It is, of course, obvious that the greatest care must be taken in the construction of this part of the filter, else the results may prove disastrous.

In the floor carrying the gravel and sand will be placed, on 6-in. centers, $\frac{3}{8}$-in. brass pipes connecting the pressure chamber with a modified form of the ordinary hemispherical brass filter strainer. Each of these pipes will bend 180 degrees just above the floor, and end in the brass strainer looking down toward the floor and $1\frac{1}{4}$-in. above it. The strainer will be a slightly buckled circular plate $\frac{7}{8}$ in. in diameter, pierced with twenty-five $\frac{1}{16}$-in. holes and swedged into a hexagonal base ending in a $\frac{3}{8}$-in. threaded pipe connection for screwing into the $\frac{3}{8}$-in. brass feed pipe from the pressure chamber. There will be 1 677 of these strainers in each filter, giving a relation between area of filter bed and area of openings in strainers of 475 to 1.

Each filter will be laid with three sizes of gravel to a total depth of 24 in., and one size of sand to a depth of 30 in. The first layer of gravel will be 8 in. in depth and will consist of that size which will pass a screen having 2-in. square mesh, and be held on a 1-in. square mesh. The second layer will be 12 in. in depth and will be that size which will pass a screen having 1-in. square mesh, and be held on a screen having $\frac{3}{8}$-in. square mesh. The upper layer of 4 in. will consist of size of gravel lying between $\frac{3}{8}$ in. and $\frac{3}{16}$ in. in diameter.

The same sand as used in the Agua Clara plant and in the new

Colon plant will be placed in these filters. This sand is the so-called Chame sand, taken from the beach south of Panama Bay and used for general construction purposes on the Isthmus. By proper washing and separation, a very suitable filter sand can be obtained, having a mean effective size ranging from .35 to .45 mm., and uniformity coefficient from 1.2 to 1.8.

The filter troughs will be constructed of concrete, and will consist in each filter of one central trough running at right angles to the operating floor and four lateral troughs emptying into same from each half the filter. These troughs have been so designed as to cause a depth of flow over their edges of 1 in. during washing. This will produce sufficient velocity of approach as to draw scum from a maximum distance of 2.5 ft., or half the distance between edges of lateral troughs.

While it is not expected to use air in connection with the ordinary operation of the filter, a separate air system will be installed between the second and third layers of gravel. It has been the writer's experience that caking of the sand bed in separated small areas can occur even in beds with high wash rates, and the assistance of air in breaking these up seems to be of considerable advantage. It may prove, however, that the uniformity of the wash from the pressure chamber system will be such as to eliminate the spotting or caking in the bed, and in this case the air will not be necessary except for the agitation and mixing as described in other parts of this paper.

The filters will be piped up in two banks of seven units each. That is to say, the piping leading to and from the filters will be in duplicate on each side of the longitudinal center line through the filter pipe gallery.

The water from the sedimentation basin will reach the filters through two 30-in. diameter cast-iron mains hung side by side from operating and office floors. Twelve-inch diameter influent pipes branching off each of these mains will connect into the filters. The wash water will be supplied through two 16-in. diameter mains running throughout the length of the pipe gallery on each side of the center line and about 7.5 ft. above the floor. Each filter will be connected off one of these lines by a 14-in. branch to the pressure chamber, and off this branch will lead a 10-in. effluent

pipe to the controller box. The rewash pipe will be 6 in. in diameter, connected directly into the sewer line through a loop rising above the level of the sewer a sufficient distance to keep back pressure from reaching the filter in case the rewash valve should be accidentally left open during the washing of adjacent filters.

The sewer lines will be two 16-in. cast-iron pipes, laid directly on the floor of the pipe gallery.

The wash water will enter the building from the 300 000-gal. tank, referred to on page 241, in a 20-in. diameter cast-iron main. Immediately back of the point where this line splits into the two 16-in. mains will be located a 20-in. Venturi meter. The recording apparatus for this meter will stand on the operating floor, so that the operator can see and record the amount and rates of wash being admitted to the filter.

All valves for operating the filters will be hydraulically operated from solid black slate operating tables, located on the operating door in front of each filter. On these tables will be mounted the usual sample cups, indicator recording loss-of-head gages, air and wash-water pressure gages, and the necessary controlling levers for the valves. Small 10-watt green and red lamps will project from the top of the tables and so wired between controller and loss-of-head gages as to indicate filter in or out of service, or ready to clean.

The floor of the operating gallery and the office and laboratory will be laid with 6-in. square dark-red Welsh tile. The breast walls of the filters will be treated with sulphate of zinc wash and painted with black enamel paint. All surfaces above the tops of these walls will be painted white.

The level of the pipe gallery floor on which the controller described below will rest will be placed about four feet below the bottom of the filters, and arrangements have been made so that the filters can be operated with or without negative head.

The head house, office laboratory, and quarters, and the filter building will have roofs of special Spanish type dark-red tile, laid on $2\frac{1}{2}$ in. of sawdust concrete, to which the tile will be nailed. The sawdust concrete will be laid on asbestos corrugated sheathing bolted to the purlins of the steel trusses.

The laboratory will be fully equipped for all work in connection with complete microscopical, chemical, and bacteriological analyses of water.

INJECTION CHAMBER.

The clear-water basin will be connected with the injection chamber by a 30-in. cast-iron main, as described on page 241. On this line will be placed a 30-in. Venturi meter which will indicate and record the flow of all water leaving the clear-water basin. The indicating-recording apparatus will be placed on the floor of the wash-water pumping station, referred to above as United States Pumping Station No. 2, located about 50 ft. distant.

The hypochlorite orifice boxes, with their measuring devices as described below, will be placed in this pump station, and from these boxes piping will lead to the injection chamber.

The injection chamber will be in a general way a concrete pressure box approximately 24.5 ft. by 17 ft. by 6 ft. inside depth, divided longitudinally into two main divisions. The water may be allowed to pass through both divisions simultaneously, or through one while the other is closed down for cleaning or for repairs.

Each division will be divided into compartments having curved and flat faced concrete baffles placed in them, of such design and arranged in such a manner as may be expected to give the utmost agitation and mixing to the water as it passes through. Upon entering the first compartment of each division, the water will pass through two vertical slots about 5.5 ft. in length by 6 in. in width, in front of which, splitting the flow, will be placed two perforated bronze solution pipes which will enter the top of the chamber through a regular stuffing box.

The water after receiving its dose of bleach will pass through the baffles into a terminal pressure compartment, and from this into the 30-in., 20-in., and 16-in. mains leading to Ancon, and into the 20-in. line leading to the suction side of the wash-water pumps in pumping station No. 2.

The injection chamber will be under a maximum pressure of 17 lb. per sq. in., and the solution of hypochlorite of lime at a strength of not more than two tenths of one per cent. will be pumped from

the measuring orifices in the pump station into the injection chamber by small bronze centrifugal pumps.

EFFLUENT CONTROLLERS FOR FILTERS.

In considering the type of effluent controller to be adopted for the filters, it was thought that simplicity of construction and operation in a controller was more to be desired than the more or less elaborate apparatus involved in certain types of controllers now on the market, and it was therefore decided to design an automatic control for the ordinary hydraulic valve placed on the effluent pipe so as to cause it to feed at constant head a bronze orifice placed in a box on the floor of the pipe gallery, and discharging through same into the clear-water basin.

The controller as finally adopted will consist of a simple round open-top concrete box, approximately 2.5 ft. in diameter and 3.5 ft. deep, cast on the floor of the pipe gallery; an adjustable circular bronze orifice cast in the floor and opening into the clear-water basin; a copper float 2.25 ft. in diameter carrying a stem which will operate a small vertical piston valve, and a 10-in. hydraulic valve placed on the effluent line leading into the controller box.

The piston valve will act on the principle of the ordinary four-way valve, and admit water, through small piping, to either top or bottom side of the hydraulic cylinder, according as the water in the controller box rises or falls in depth over the orifice. The depth of water for any rate of flow from the filter on the orifice having been determined, and the float set at this height, the hydraulic valve upon being opened, admitting water into the box, will be actuated in such a way by the piston valve as to maintain a constant head on the orifice through conditions of maximum to minimum heads from the filters.

The small piping from the piston valve to the hydraulic cylinder has been so arranged with branch piping to the regular four-way valve on the operating table that the filter can be cut in or out at any time by throwing the four-way valve lever on this table; at the same time automatically cutting out the operation of the controller piston valve.

To change a rate of filtration, it will be only necessary to raise

or lower the controller float to correspond with the increased or decreased head desired on the orifice to give this change. The action of the 10-in. valve is necessarily rapid, and the filter upon being thrown into service after cleaning will go almost instantly into its fixed rate of discharge and maintains the rate constantly until the effluent valve reaches its full open position.

ALUM AND HYPOCHLORITE OF LIME APPARATUS.

As stated in the description of the head house, the hypochlorite and alum solutions will be prepared on the third floor of this building.

The alum will be placed after weighing on a removable wooden floor over the top of the solution tank. This floor will be bored with $\frac{1}{4}$-in. holes, $\frac{1}{2}$-in. on centers. The alum will then be dissolved by heavy sprays playing upon it until it has passed into the tank beneath.

Agitation of the solution will be accomplished by an ordinary motor-driven adjustable bladed bronze propeller running in a conical-shaped compartment placed on the floor of the tank. This compartment will be ported and the solution will be drawn in at the top and driven out at the bottom through these ports. The propeller shaft will be driven by a $7\frac{1}{2}$-in. h.p. motor through a bevel gear and rawhide pinion. The thrust bearings for this shaft will be placed at the top of the tank so that the bottom end of the shaft will run in a simple guide bearing and thus eliminate bearing troubles that would arise from the action of the solution on the metal parts of a bearing placed at the bottom. The solution will be carried from either of the two solution tanks through a 2-in. bronze pipe leading directly into a constant head regulating box placed on the second floor of the head house. This orifice box with its regulating devices will be in duplicate so that repairs or cleaning may be effected without interruption to the supply of solution.

The solution will enter the orifice box through a bronze ported cylinder within which will work a movable shell attached to a vertical spindle ending in a copper float about 20 in. in diameter and 4 in. deep. This cylinder will be $2\frac{1}{2}$ in. in diameter and the

cylindrical shell will be $1\frac{1}{2}$ in. in diameter. A movement in the vertical plane of one quarter of one inch will give full flow into the box, and this will be the amount of variation in head on the orifice outlet from maximum to minimum flow.

The orifice measuring the flow passing from the controller box to the perforated pipes over the raw water will be an annular slot with a movable cover placed over it, which when revolved about its center will throttle the slot in such a manner as to change its size in its circumferential dimension only. This cover will be actuated by a vertical shaft leading to the top of the controller box wall, where it will end in a gear and pinion and indicator pointed controller handle. A horizontal plate placed immediately above the gears, below the indicator, will be divided into degrees of opening of the orifice slot, and the indicator or pointer will give the exact opening in degrees on the plate. The gear and pinion is introduced for multiplying the angular motion of the orifice cover by two, so that a small angular throttling of the orifice can be obtained.

The solution in passing the orifice will fall into a small concrete trough, in the sides of which will be placed three bronze sharp-crested weirs, $1\frac{1}{2}$ in. to 2 in. in length, placed at exactly the same elevation. These weirs correspond to the three mixing chamber units and serve to split the solution equally into two or three parts according as two or three mixing chambers are in operation. The solution will fall from these weirs into $1\frac{1}{4}$-in. bronze pipes ending in perforated pipes placed directly over the discharge from the weirs delivering the raw water from the aëration basin into the mixing chambers. The solution will thus finally be delivered to the raw water in 30 to 90 $\frac{3}{16}$-in. diameter streams, spaced about 6 in. apart.

The hypochlorite of lime will be delivered to the storage room set aside for it on the upper floor of the head house in 50 lb. containers. The lime will first be reduced to an emulsion and then admitted through screens to the solution tanks, where it will be brought to a strength from one tenth to two tenths of one per cent. There will be three emulsion tanks constructed throughout of bronze. These tanks will be approximately 24 in. square by 20 in. deep, with cylindrical bottoms and watertight covers.

They will be placed in line on the floor of the storage room about 10 ft. distant from the solution tanks. In the horizontal axis of each box will be placed a shaft passing through the sides and carried in watertight bearings. In this shaft will be placed stirring blades with about $1\frac{1}{2}$-in. faces. These blades in revolving will pass between baffles projecting from the bottom of the box. The clearance will be such as to break all particles to at least $\frac{1}{2}$-in. size. The shafts will end in pulleys which will be driven by belts running off tight and loose pulleys carried on a line shaft placed in the rear and parallel to a common axis through the three boxes. This shaft will be direct connected to an induction motor.

Each box will be equipped with fixed water connections for filling, and with a water ejector which will deliver the emulsion from the box to the solution tanks without any handling beyond the turning on of the ejector valves.

One or two 50-lb. batches of lime will be placed in the emulsion box, the cover clamped down, and the water turned on until the box fills. The mixture will then be stirred by the blades on the shaft revolving at high speed for a few moments, and finally the emulsion will be ejected directly into the covered solution tank, where it will be further mixed by compressed air for a period of one hour, and then allowed to stand until thrown into service.

Experiments with this character of apparatus indicate that a minimum of handling and exposure to the air, and consequently a minimum of fumes, may be expected during the operation of preparing the hypochlorite solution.

In order that it might be possible to have the indicating recording apparatus of the Venturi meter on the 30-in. effluent line from the clear-water basin immediately adjacent to the hypochlorite measuring boxes and orifices, it was decided to put both in the wash-water pump station near the injection chamber. It was also decided to place the solution orifice under constant manual control according as the meter indicated the flow, instead of attempting any automatic device.

The solution will be delivered to the pump station controlling apparatus in either lead or bronze pipes. It will be discharged through an hydraulically controlled sliding hard-rubber orifice into a small float chamber, and by means of a float and piston

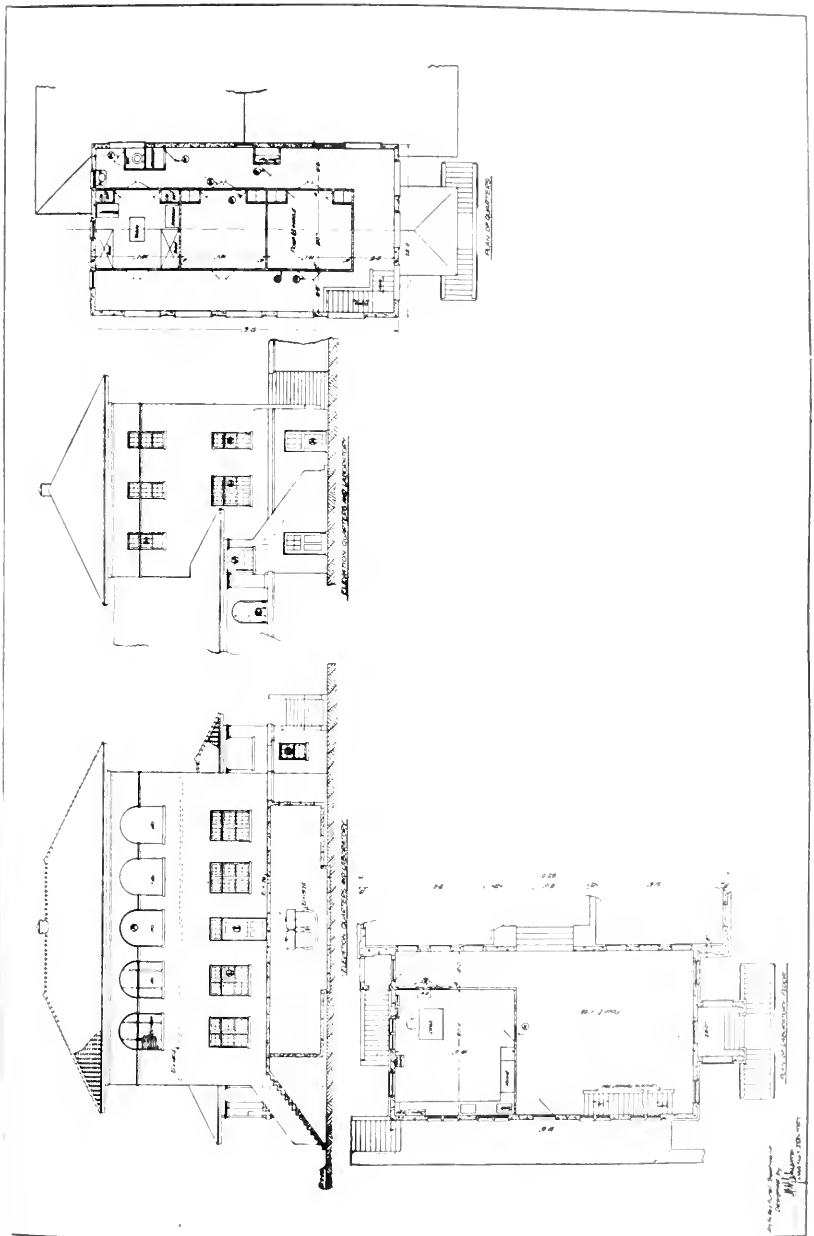

Fig. 4. Office, Laboratory, and Quarters.

valve operating the hydraulic cylinder of the orifice a constant head will be maintained. In the wall of this float box will be placed a hard-rubber orifice, which will be varied in opening by means of a milled head screw manually operated. An indicator scale reading to thousands of gallons per minute will be placed above the orifice and so graduated that for a certain fixed head on the orifice and for a certain fixed solution, the desired amount of chemical will be delivered for any flow indicated by the meter by simply setting the orifice indicator to read on the scale the same as indicated by the meter indicating apparatus.

The solution passing this last orifice will fall into a small open chamber from which it will be pumped by a small centrifugal pump into the injection chamber.

The entire chemical measuring apparatus described will be installed in duplicate.

The hypochlorite measuring apparatus recently installed at the Miraflores temporary pumping station is similar to that described except that pumping is not necessary, and has given very satisfactory results. The presence, throughout the twenty-four hours, of an attendant whose duty it is to keep the orifice scale reading the same as the meter and to keep a log on both gives reasonable assurance that the flow of chemical meets the fluctuations in the mains; and further, in the event of anything going wrong, it is immediately noticed and remedied.

The cost of such attendance on the isthmus is low, as satisfactory services can be obtained from West Indians at thirty-five dollars per month on a twelve-hour shift basis.

The operating force for the purification plant will consist of one chemist, two filter operators, two head-house men, and one hypochlorite orifice attendant. The chemist will be required to be a trained water analyst, with experience in handling plants of this character. The others on the force will be West Indians who, it has been found, can be developed into reliable operators for the straight mechanical work of manipulating valves, etc. The plant will be run on two twelve-hour shifts and with full force for both shifts.

The estimated cost for this plant figures out approximately \$22 000 per million gallons of water delivered per twenty-four

hours. In considering this, however, it should be noted that the comparatively long sedimentation period calls for a large and correspondingly expensive basin. This, together with difficult topographical features encountered, requiring the placing of the plant on a high, narrow ridge, and also with the more or less elaborate aëration treatment not ordinarily embodied in plants of this character, makes for a figure per million gallons delivered per day that may at first glance seem a little higher than usual for plants of this type and capacity.

THE CONSTRUCTION OF DAMS.

BY A. E. WALDEN.*

[*Read September 9, 1914.*]

There are many things to be considered in designing dams, and especially one of the commonly called "gravity type," or, rather, of the solid masonry type, which will be here called the mass type; the gravity type will be that as constructed by Beardsley and Amburson and Ransom.

There are many dams that have been constructed on foundations so unsafe that they would be immediately condemned if they were to be proposed and erection started to-day.

In making examination of a dam site, test pits or borings should be made for a good distance above the dam site to determine the composition of the soil or strata under the dam, the trend of the stream, if on rock, noting if these are at right angles to the stream or with the stream, and if the stone is subject to water holes; also the character of the ledge, whether seamy or not, and if it shows rapid disintegration where exposed to the atmosphere, and if under water, that it is easily worn away by the action of the water, as in some limestones.

In some cases it will be found that in the bed of the river there are two classes of stone, one portion of which is soft and the other hard.

A careful examination of the banks should be made for suitable abutments and abutment foundations, and the quality of the soil composing them; also the slope of the underlying rocks, so that steps may be taken to prevent seepage through and eventually a washout.

There are several ways that have been employed by engineers in determining the proper length of crest, all of which are more or less efficient when properly applied, as are also certain empirical

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rules, where run-off data cannot be obtained, such as basing the run-off on a certain number of feet per second per square mile, certain instances of which will be given here.

In one case that came to the writer's notice the dam was constructed on a basis of three feet of crest per square mile of area which is hilly and steep, based on a rule that there should be on normal conditions at least one foot of spillway length for each square mile of drainage area, and this multiplied by three can take care of flood conditions. This dam failed many times, causing great property damage, but was finally constructed so that the spillway section would have a crest equal to taking the run-off at 20 cu. ft. per sq. mile at a velocity of one foot, and dividing this result by an assumed depth at the crest, considering it as a rectangular section, no allowance being made for the well-known weir action and of velocity of approach over such a crest. No trouble has since been experienced. This determination was made after an examination of the stream's banks for height of water, its depth at this point as compared with the width and depth of water at other points and for several hundred feet above and below; also noting the heights to which débris had landed; from information given by people living along the stream as to flood heights; from the drainage area and from rainfall data which had before for some reason given results too small, to some extent probably due to the character of the drainage area, its topography, and the condition of the soil at certain times.

With 20 cu. ft. at a velocity of one foot per second and the banks 5 ft. high, it was assumed that the water reached 5 ft., but with 20 cu. ft. used as a basis and the dam lengthened to 146 ft., and estimating a crest depth under these conditions of 3 to 4 ft., this stream has since been measured for surface velocity during high water and an average velocity, on the surface, of 10 ft. per second obtained, with a depth of 20 in. at a point far back of the crest so that the increased velocity of the water at the crest of the dam did not affect it. Undoubtedly the velocity of the water varied at various depths, but this could not be obtained.

Assuming the average velocity at 10 ft. per second, and a sectional area of 146 ft. by 20 in., the approximate discharge per square mile in this case was 99 cu. ft. per second, and the greatest

depth of water so far noted on the crest of this dam has been 3 ft. It is possible under these conditions that the velocity was from 15 to 20 ft. per second, but this could not be measured at the time, on account of lack of preparation.

In another case a dam was constructed for a crest depth of 5 ft. for a drainage area of about 300 sq. miles. This dam was 200 ft. long at the spillway, with about 1 000 ft. of earthen embankment about 18 ft. higher than the spillway section. The 5 ft. depth at the crest has been exceeded many times, and the gage has shown a depth of $11\frac{1}{2}$ ft. on the crest, which was beyond data based upon the government report's gage readings at that time, and would be about on the approximate basis of 7 cu. ft. per second per sq. mile.

From an examination of many streams, watersheds, and dams, it would seem that one may expect to find that the run-off will vary from 50 to 100 ft. or more per second, and in some cases it has been considerably more than the maximum amount noted for a hilly section, that will give a quicker crest rise than a flat section will do, owing to the fact that the water cannot spread over any large area.

It may be assumed that a certain portion of the flood reaches the crest in the first hour, a certain portion in the second hour, and so on to five or six hours, or more, but this cannot be accurately determined beforehand with the data we have to-day.

Every effort should be made to obtain data from other dams on the same watershed, if any, or on similar watersheds in the vicinity, as to the rise in a given length of time after a heavy rainfall, so as to determine the lapse of time between either the beginning or the maximum rainfall and the maximum crest rise. Rainfall data show that a maximum rainfall of 4 in. in one hour may be looked for, and from 8 in. to 10 in. in twenty-four hours. On this basis there would fall for each square mile in the first hour, 9 288 800 cu. ft. (1 in. equals 2 322 200 cu. ft.). Then the question would arise as to what part of this reaches the dam the first hour, and each succeeding hour until the maximum crest height is reached, and the effect the condition of the soil and the ground water content has on this. From J. B. Francis' records, the indication would seem to be that a depth of rainfall varying from 6 in. to

11 in. or more, with rates about as follows, may be looked for: 4 in. in two hours, 6 in. in about twenty hours, and 9 in. to 10 in. in thirty hours, etc.

For the rainfall and flood conditions, Fanning's formula has been much used, as well as others, but must be applied with care for the particular location, the period of the year in which the rainfall occurs, as on frozen ground or with a light fluffy snowfall it requires 15 in. or 20 in. to equal 1 in. of rainfall. While assuming 4 in. to 5 in. of wet soggy snow to equal 1 in. of rainfall, the rainfall combined with the water from the melting snow with the frozen ground underneath will give quite sudden changes in the flood conditions, which will exceed any rainfall obtained from hourly rainfall records; recording gages at dam, however, would show this.

The effect of impoundings or pondage in reducing flood conditions, if the area is sufficient, where there is one or more dams above the one to be designed, should be considered. The crest of the dam under design should be proportioned to care for the failure of at least one, or more, of these dams in addition to that of flood conditions, depending on the location of towns and villages

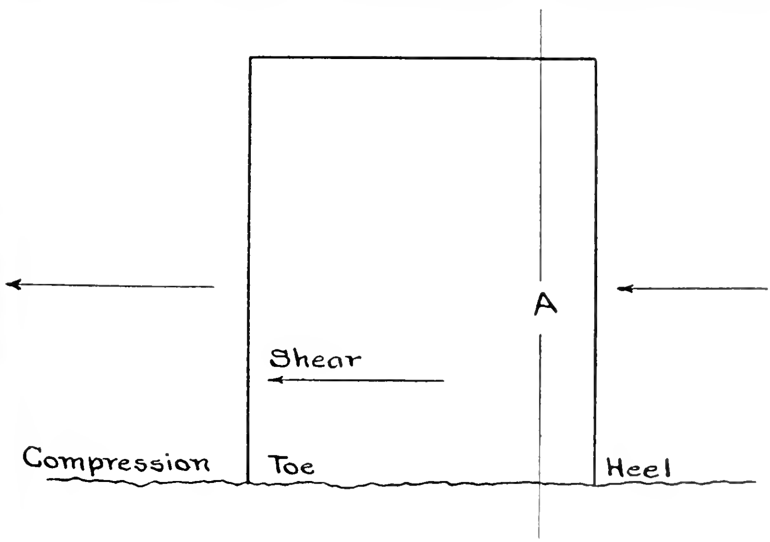

Fig. 1.

below, and the property value and loss of life likely to occur in case of such failure.

In the design of a dam of the mass or solid section type, as shown by section, Fig. 1, the dam may be considered as a beam fixed at one end and having an uniform load, and as such may have shear at the joints, tension in the upper face and at the heel, with compression at the toes, etc.

Then to care for tension in the upper face, steel may be provided, but its calculation would be to some extent theoretical. In any event, if securely anchored to the rock formation in drilled holes, and the steel provided with split ends and wedges, and afterward grouted in carefully, this method would certainly add to the stability of the dam, especially when the dimensions were properly proportioned to care for shear. Steel bars may be embedded at an angle of about 30 degrees, as shown in Fig. 4, or some other angle, with the horizontal so that the steel will take tension as far as it is possible to make it do so under these conditions.

In preparing the foundation, care must be taken to remove surface rock that has deteriorated, to a depth that test holes show to be safe, and then the surface under the dam should be roughed, either toothed or sawtoothed, or in a similar fashion, so that pressure will tend to force the dam downstream and against the toothed or roughed surface as shown.

This work should be carefully performed, either by the use of dynamite or steel points and wedges, but dynamite should be used in the hands of an experienced man who understands placing shots, and especially is this true of the cut-off wall at the heel, for if such placing is done, it should be carried out in the manner

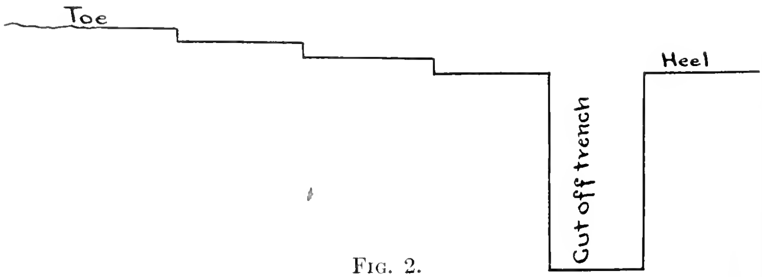

Fig. 2.

described, care being taken to so set the upper drill holes to line for a narrower cut than is required, and then remove the shattered stone by wedges and points, as it is necessary that the cut-off wall should not be shaken to such an extent that there will be liability of leakage to the downstream side.

A careful note should be taken to see if seams run at right angles with the stream, or partially with the stream; also the character of the stone and of any change in the composition, as there are cases where there are one or two different rock formations in the same river bed.

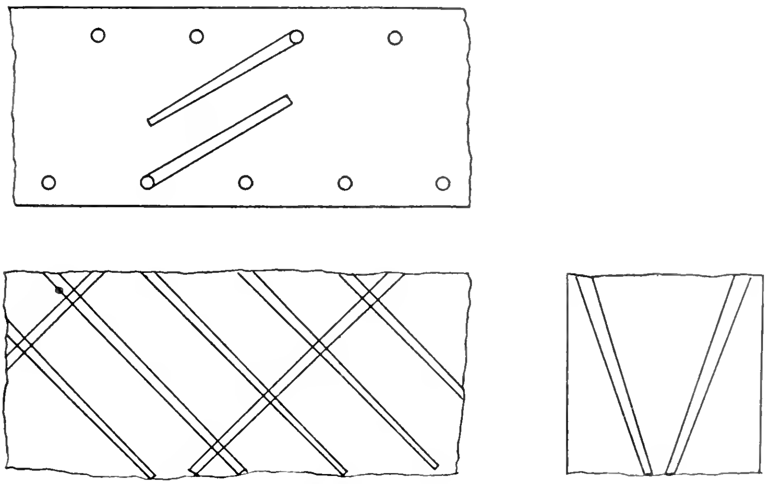

FIG. 3. METHOD OF DRILLING.

One or two test holes should be exploded with various charges, at some other point, to determine the proper charge to be used, but vertical holes should not be used, unless absolutely necessary. In this respect it might be said also that a regular 500-volt current will explode twenty holes, and such a number of holes exploded simultaneously will do better work than three or four holes exploded at a time. Holes may be placed as described below:

Holes running with trench on each side, about 4 ft. apart and at an angle of 45 degrees, with extra holes at each end at same angle, looking the other way. The depth of these holes will depend

on the depth of trench required and the width of the same. In addition to this, holes may be drilled from side to center as shown in the end section, Fig. 3.

The writer has seen trenches cut in this manner, by men who understood tunneling and channeling, that would meet the conditions required in every respect.

Test holes should be drilled to sufficient depths, 10 to 20 ft., more or less, to be sure that no seams or underlying strata of clay underly the rock, and tested with compressed air or water to at least 100 lb. pressure, and pressure maintained for such a time as will surely determine the condition in these test holes. Shale formations are liable to large seams; overlying strata of clay and limestone formations to water channels or recesses. The holes should be drilled from 10 to 15 ft. apart, more or less, depending on the conditions found to exist.

There seems to be no reason why solid section dams should not be constructed in the form of arches that extend from the toe to the cut-off wall, and the spaces under these arches would effectually care for any uplift due to water seeping through or under the dam, supports to the arches, or haunches of the arches, of course, being carried sufficiently below the surface to effectually protect them from wash and undermining, and would be more satisfactory than large pipe placed 8 to 10 ft. apart, more or less. Or 10 in. split tile may be employed for this purpose, which would be more satisfactory than a solid tile, but in any event should be covered with loose stone so as to allow free access to the tile from all sides.

There is another condition that must be given consideration in this work, and that is, at the toe of the dam there will usually be found a pool cut out in the rock or other surface, that at or near the center of the spillway section will have a depth of from one third to one fourth of the height of the dam; and it will be found that if this pool is filled with concrete, it will eventually wear to this same depth and there remain about stationary. It would seem to be good policy to retain these pools, unless some other method were taken to care for the action of the water at this point. Some types of dams would probably be less affected than others.

The solid dam may be reinforced and tied to bedrock in the

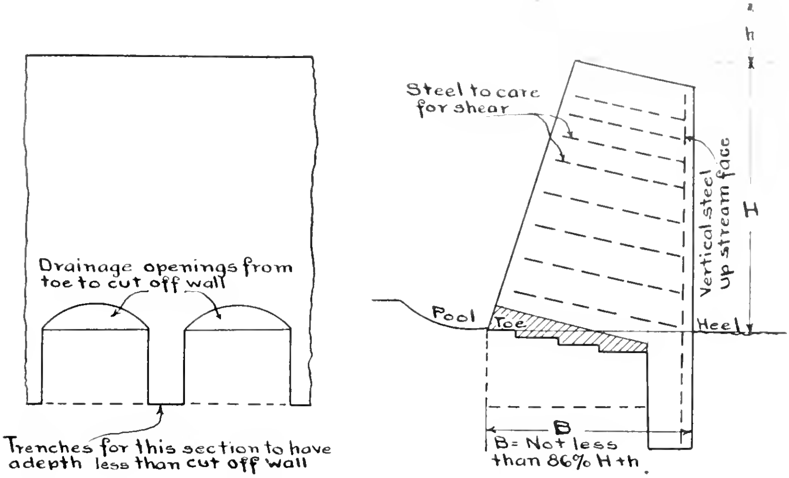

Fig. 4. Section of Solid Dam showing how the Arch can be Used for Drainage from Cut-off Wall to the Toe.

cut-off portion, as described before and as shown here, and thus would take tension in the upstream face of the dam, in addition to which the diagonal bars at some angle would tend to take the tension due to sheer and prevent any tendency to sheer in the horizontal plane, or where new work was tied to old, in case that the joint was not properly cleaned.

The trenches for the haunches for the supports of the arches should have a depth at least equal to the pool and the cut-off wall, preferably somewhat below this. These arches should extend back to the cut-off wall, which should be made sufficiently strong for the purpose, and will give a more efficient drainage than it will be possible to obtain with pipes of any kind.

Referring to the earthen embankment as employed at the abutment ends of some dams, the following construction was employed by the writer, and tests carried on every day for several years to see if there was any increase of the water in the test well, Fig. 5, but no increase was found.

Again, from the core out to the toe every 20 ft., double lines of porous drainage tile were laid from the double line of tile that skirts

the core to the double line that skirts the embankment just under the toe and to the outside of the embankment to some suitable disposal point that would allow of the amount of water running to waste to be measured, from time to time, these drains being covered in turn with crushed stone to a depth of 6 in.; the reason for this being that the writer excavated on one such embankment to the center of the same, the embankment being composed of a gravelly soil, and found no water until the center of the embankment, or core, was reached, showing that the drainage kept the embankment dry from a point above the center to the outside.

As before stated, the surface or foundation on which the dam or embankment is to be constructed should be excavated either in trenches or as shown, as this gives the foundation a greater frictional or sheering resistance.

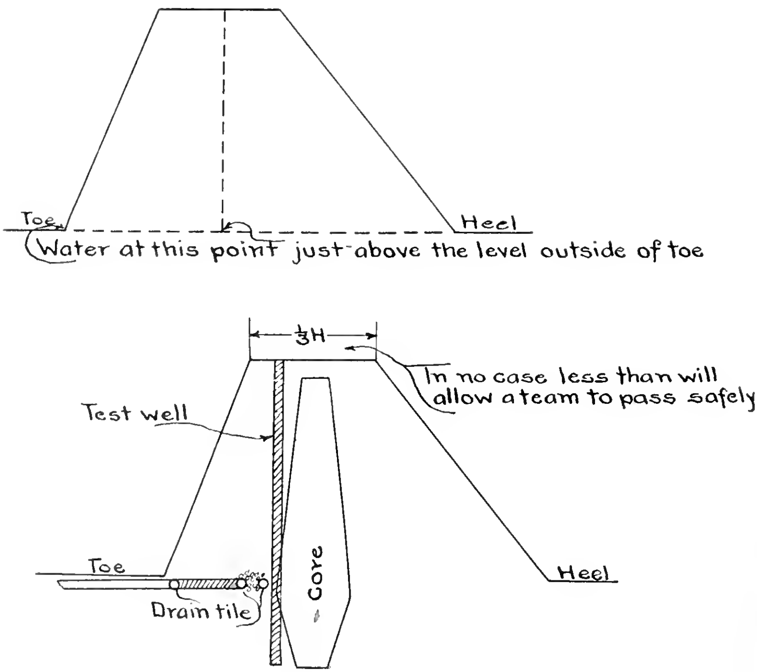

FIG. 5.

Table 1 gives data on dams, the depth and velocities of waters at the crest for which these were designed; and the actual depth obtained will give an indication of the conditions as they actually exist.

TABLE 1.

Dam.	Square Miles.	Velocity of Approach. Feet.	Designed for Crest Depth. Feet.	Actual Crest Depth. Feet.	Length of Spillway. Feet.	Estimated Maximum Run-off Cubic Feet per Second
1	4 185	8.5	9	16.5	1 000	50
2	4 475	8.5	13.5	14.4	1 000	50
3	3 085	..	16.4	18	1 000	..
4	1 545	8	8	9.5	890	60
5	7 000	..	6	...	318	..
6	19 600	..	12 and 5	...	1 500	..
7	66 000	..	12	10	700	..
8	1 380	..	7	2.2	400	..
9	5 760	..	15	12	1 078	..
10	400	..	5	3.6	120	..
11	3 560	..	(Could stand 9; stand flood of 50 000 sec. ft.)	4.4	1 108	..
12	15 800	..	15	...	480	..
13	16 600	..	15	...	500	..
14	1 270	..	5.5	8	260	..
15	.....	..		...		..
16	26 766	..	17.5	...	2 350	..
17	300	..	5	11	200	..
18	320	..	5	8	119	..

Dam No. 18 was designed to care for 4 400 sec. ft.; had a total crest length of 450 ft. and a spillway section of about 120 ft., and under flood conditions water rose 8 ft. above spillway section and 3 ft. over the crest, the estimated discharge being 14 500 sec. ft.

There is one other point in the case of gravity dams, Fig. 6, in that the factor of safety of 4 for deck loads has been used, but consideration should be given the following sketch (Fig. 6), also the cost of such work. It is manifestly certain that no load will ever be obtained that would stress the deck to call for a factor of 4, or even a factor of 2, and that a factor of $2H$ would be amply safe even for ice, as with a sloping deck such a factor would protect it from floating blocks or a plane of solid ice, as the blow would be

glancing; and again, the silt which fills in on the deck would act as a cushion. Then again, floating objects are most apparent at flood when the water on the crest is deepest, which would tend to carry these floating objects safely over the crest. And in any event, the stress in the material would not exceed the normal load stress effect. It may be said that load stress is uncertain. This may be true of some dams.

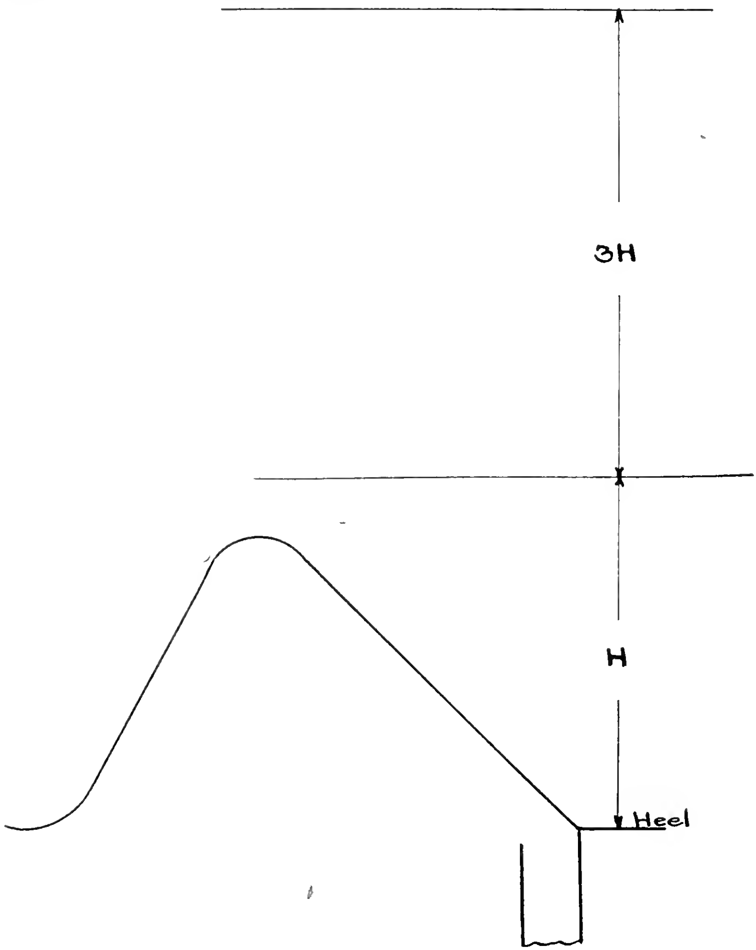

FIG. 6.

Now, the writer is not advocating a construction that would be unsafe under any consideration, but that more careful consideration be given these conditions on account of cost in a safety factor for loads that would be both safe and economical in so far as the cost of material and construction were concerned, but without going to extremes for a condition that will never be reached.

Records should be kept of the depths of the waters on the crest of the dams at all times, and the cost of an efficient instrument for this purpose is small; the one in the cut here (Fig. 7) shows a simple method of obtaining such records, which, together with the records for rainfall, and comparing the depth of rise on the crest of the dam and the time relative to the maximum rainfall would give data that would be invaluable, in a short time.

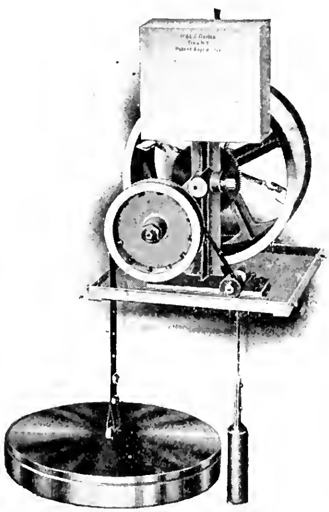

Fig. 7.

Records should also be kept of the soil strata through which excavations for test pipes and test holes pass.

The question of frost at times may have to be considered.

Every available record should be used to determine the run-off from the rainfall on a given watershed, as the run-off and the time of the maximum run-off are affected by so many conditions

that there should be as few guesses as possible, and even the records should have a reasonable percentage added.

Acknowledgment is hereby made of the assistance and data given by the following engineers in the preparation of this paper: H. N. Savage, M. H. Gerry, C. A. Mears, A. E. Peirce, H. W. Connell, J. C. Lathrop.

THE AUTOMOBILE AS AN EFFICIENCY AGENT IN WATER-WORKS MANAGEMENT.

BY GEORGE W. BATCHELDER, WATER COMMISSIONER, WORCESTER, MASS.

[Read September 10, 1914.]

In these times of improvement in all directions, the automobile is recognized as an agent of speed and efficiency in the transporting of men and materials.

The city of Worcester has long been known as conservative to a great degree, and it was not without considerable sharp criticism that the first municipal automobile was put in commission.

Worcester has changed, and is changing rapidly, from a condition of extreme conservatism to a live, pushing city.

The first automobile put in service for the Water Department was purchased in February, 1909; there are now eight machines in service, but the equipment is not quite complete.

These automobiles are numbered from one to eight, and will be so mentioned in this paper.

The costs given cover, in all cases, every expense except for the operator and stable men.

Depreciation is figured at 20 per cent., interest on investment at 4 per cent.

No. 1 car, a two-cylinder Buick equipped with a light express body, was put in service early in 1909. It was used as a meter and light repair machine and was available for emergency service at other times.

After five years of good service the little machine was consigned to the junk pile to make room for a Ford car, now about to go in commission.

During its service it carried the men to practically every meter job and to many repair and emergency jobs.

The meter service trips alone numbered 4 446 in 1909, 4 040 in 1910, 4 008 in 1911, 6,094 in 1912, 4,752 in 1913. The aver-

age daily run of this machine was about forty-five miles, — work which would require three horses.

The cost of this machine when purchased was $1 000. It cost to operate, all expenses, $1 048 a year.

No. 2 car: A four-cylinder Buick, Model 17, was bought in 1910 at a cost of $1 750.

This car is used to transport engineers and office men from the city to Kendall Reservoir, where the engineering department has been for several years engaged in constructing a dam and reservoir.

The car at other times during the day is held at the reservoir for ambulance service, or used to transport light supplies.

The value of getting the engineers in charge of any work on the job early in the morning is known to everybody. The automobile gets them over the nine miles from City Hall in short order, — twenty-five minutes instead of seventy or eighty minutes, if horses were used. The cost of operating and maintaining this machine is $1 200 per year.

No. 3 car: A Buick automobile, Model 21, was purchased originally as a touring car and later changed to a service car. It is now used for meters and light repairs, taking the place of the original No. 1 truck. Its average run is forty-five miles daily. It costs to operate and maintain $1 290 a year.

No. 4 car: A four-cylinder Pope Hartford touring car was purchased in 1913, at a cost of $2 025. It is used by the Water Commissioner and city council committees.

By having this car available, the commissioner is able to keep closely in touch with outside matters of any particular importance.

Four construction gangs are usually laying pipe in different sections of the city. Their work is inspected by the commissioner at least once every day.

The reservoirs, of which there are nine, are visited and inspected several times weekly, and frequent general inspection of the plant is made possible by the automobile.

Inspection trips of this nature cover an average of 35 miles daily. It would take two horses to do this work, and the commissioner would be in the saddle practically all day, and there would be no time for office hours.

It has been the practice to rent this machine for the use of the city council committees, for which a revenue of about four hundred dollars yearly has been received. This custom no longer exists, however, as the car is kept busy in the Water Department service. This car costs, all expenses, $1 280 per year.

No. 5 car: A Model 31 Pope Hartford touring car chassis with a truck body was bought in 1913 at a cost of $1 800; the body made the total cost $1 925. It is constructed with hangers outside the body, so that several lengths of service pipe can be carried, together with men and tools for installing services. This car makes it possible to get the work started early in the morning, long before it could be done if horses were used.

There are frequently five service-pipe gangs working in different parts of the city.

The foreman in charge, who operates the machine, makes frequent trips from one job to another, sees that his men are keeping the work going as it should, switches some men from a job which may be practically finished to another which ought to be closed at the end of the day, and picks up what would be a lot of loose ends if he had to depend on horses. The daily average run is about 45 miles. The cost of installing service pipes has been reduced about 10 per cent. since this automobile went into service. The total cost of operation and maintenance has been $1 262 per year.

No. 6 car: A Pope Hartford three-ton truck equipped with extra-size dual rear wheels makes it the equivalent of a four-ton truck. This car has been loaded many times with forty eight inch pipe weighing 8 800 lb. or more, and has been in service practically every working day since its delivery in March, 1913, with the exception of a period in March, 1914, when heavy snows made the operation of an automobile impracticable.

Advantage was taken of this lay-off to overhaul and paint the machine.

Before this truck was purchased the department contracted the hauling of water pipes to the various places required. In 1912, the year before the car was purchased, the Water Department paid contractors for teaming the sum of $2 700.

In 1914, if the same rate prevailed per ton, the volume of busi-

ness would make a bill of \$8 500 for the same kind of service. Deducting from that \$1 352 paid for teaming this year leaves the truck performing a service worth \$7 148, — figures which seem very large, but they are correct. It should be understood, however, that the pieces hauled in 1912 were, many of them, small, which took time for loading and unloading; the great bulk of tonnage in 1914 is made up of single and very heavy pieces, one to a load.

An example of precise comparison between the work of horses in 1912 and auto truck in 1913 is furnished by these figures:

Horses, 1912, 7 pairs, 14 pieces 48-in. pipe hauled daily.

Auto truck, 1913, 14 pieces 48-in. pipe hauled daily.

Our truck doing the work of seven pairs of horses on the same haul over identical roads, the same loading and unloading conditions.

Cost seven pairs horses and drivers, \$38.50 per day.

Cost auto truck, operator, and two helpers, all expenses, interest, depreciation, etc., \$13.86 per day.

The truck has hauled, this year, from March 26 to August 31, 4 692$\frac{3}{4}$ tons, a distance of 5 312 miles. The greatest day's work was 101$\frac{3}{4}$ tons of 36-in. pipe hauled 40 miles.

Conditions for a comparison between horse and auto trucking could not well be more clearly defined than in this example. With heavy materials, long hauls, and plenty of work to do, the auto truck completely outclasses horse-drawn vehicles.

No. 7 car: Ford runabout, used by general foreman. Two horses were required for this work. The foreman covers all his work, which is practically double the amount done when he used two horses, and he has more time to look after things at the water shop. This car costs per year, all expenses, \$291.

No. 8 car: Velie 1 500-lb. truck, used for general light work. Capable of handling with ease materials weighing over a ton. This car has not been in service long enough to furnish any accurate figures of cost.

This completes the automobile equipment of the water department at the present time. Other cars will be added later as means will allow.

The efficiency of these automobiles cannot be measured in dollars and cents.

No. 1 car greatly improves the promptness of service for which it is intended.

No. 2 car carries the men to the reservoirs promptly and starts the work early in the day.

No. 3 car renders service greatly superior to that given by horses.

No. 4 car, the advantages have already been explained, as have those of No. 5.

No. 6 auto truck needs not further explanation after the example shown.

Nos. 7 and 8 cars have shown their worth.

Collectively, these machines are of great value. There are few moments in the day when several of them cannot be readily reached and rushed into emergency work. Every water-works man knows what that means when a serious break occurs — and who has not had that experience?

The responsibility which makes water-works superintendents desirous of giving good service and furnishing first-class fire protection at all times should be helped by giving them a good plant with which to do business. The automobile plays a very important part in this direction.

It costs money to maintain and operate automobiles. One serious break in a water pipe might cause a loss which would make the automobile expense seem trifling, and for that reason alone it is well to be equipped with good apparatus.

CALKING JOINTS WITH AN AIR COMPRESSOR.

BY DANIEL J. HIGGINS, SUPERINTENDENT WATER WORKS, WALTHAM, MASS.

[*Read September 10, 1914.*]

My first knowledge of the air compressor was some twenty years ago, and at that time the term air compressor loomed up mighty big to me. I was at that time a pattern maker, and the air compressor was for the famous firm of engineers, Westinghouse, Church, Kerr & Company. It was considered quite a thing to make the set of water-jacket cores which have to surround the main cylinder for cooling.

From that time on, air compressors have crossed my path in many ways. I have had four years' experience in the United States Navy, and the work that the air compressor performed in marine work was phenomenal. The compressor plant is located in any available place, and so arranged that with the hose connection, can transmit power strong enough to drive tools in isolated places. In marine work, especially in the work of drilling, riveting, and calking of the steel sides of our battleships, it is a very wonderful operation. To-day they have so ably handled the tools that a very light and powerful tool in the hands of a skilled man does a phenomenal amount of work as compared with that done with hand tools.

Air compressors are also largely used in structural work and in the machine shop. In the foundry they are used for sand-blasting castings, running molding machines, and operating air tools.

Last year, we had occasion to lay about ten thousand feet of 10-in. pipe. After making the necessary plans and estimates, I happened to get in touch with a manufacturer of air compressors, and there were some things in the small machine they offered which appealed to me for calking lead joints. The main features were that it was portable, not too heavy, and with enough power to run the calking hammer comfortably. The whole outfit cost

less than $450, and showed in the end that this one job almost paid for the machine. The first cuts which were shown me did not appeal to me particularly, as they showed a wooden bed. I took up the matter with the manufacturers and asked to have this machine made on a channel iron bed. This was done, and since that time all machines are made with channel iron beds. They had certain claims for the wooden bed but after having our channel iron bed under severe usage, I was convinced it was the proper thing.

The machine which we purchased was directly connected with a single-cylinder, four-cycle gasoline engine, pumping directly into a vertical tank placed on the same bed. On top of the tank was arranged a safety valve and an air valve. Beyond the air valve was a slip joint and lock coupling for air hose. We had fifty feet of hose, and by placing the machine on the street beside the ditch, opposite the side where the gravel was to be thrown out, we could calk 100 ft. or practically eight joints without moving the machine. In one 5 000-ft. section, we ran across about 1 000 ft. of ledge, and rather than call in a contractor, or drilling the ledge out by hand, I decided to buy an air drill. This cost about $68, with a set of drills, and we removed 1 000 ft. of ledge. We found this was a very good investment, as we have used the machine many times since then for removing ledge, and have also found it profitable to transport it to various points in the city to remove large bowlders when we ran across them in the trenches.

Now, as to calking, we used the best Omaha lead, and instead of a straight ell, we used a beveled one, because it was necessary to have more lead protruding slightly beyond the bell end when calking with the machine. This would seem to indicate that the lead was more firmly forced into the joint, and we have never split a bell. The length of time necessary to calk a joint was nominally about three minutes to the joint, as compared with fifteen minutes under former conditions. Our first calking tools were made a trifle long, and after experimenting with them, decided that a short tool was more practicable. At first our calking gang was a bit timid in using the machine. They were under the impression it was going to cheat them out of a job, but after

a few demonstrations, they realized the machine was a powerful aid to them, and later realized the wonderful power behind the blow of the air hammer. We found that under-side calking was made much easier on account of the hard position and reaching that calkers had to assume in order to do satisfactory work under old conditions. The machine works just as well underneath as on the sides and top, where access is much easier.

In my first crew we had a fairly intelligent man to run the machine and to lend a hand in setting the pipe. I found at first that this man was addicted to the very serious habit of using a screw driver and monkey wrench on the machine, and would not do as he was told. This lasted several days, and we finally had to let him go. A high-school boy, formerly water-boy for the gang, was taken and put running the machine with the same instructions as given the former man. He proved a wonderful success and followed instructions to the letter, and we had much better results than at first.

The portable air compressor differs from all other plants of this kind as the engine and the compressor are combined in one machine. The air piston is connected on the same crank shaft as the engine piston, making what is known as a double throw method, which gives absolutely the same speed and power to the compressor as the engine. Another improvement is the piston discharge valve instead of the old-style stem-valve, which makes it possible to reduce the valve space behind the air piston to a minimum. This valve also increases the efficiency about fifteen per cent. and is practically indestructible. The compressor is also equipped with an unloader which automatically relieves it at any desired pressure up to 125 lb. The engine is equipped with a magneto which makes the use of batteries unnecessary. The gasoline supply is retained in the base of the engine.

The requirements of a properly calked joint involve a rather tedious and slow operation when performed by hand. In addition, it is expensive and lacks uniformity and reliability. This is most noticeable on the under side of a joint due to its inaccessibility. The pneumatic hammer gives an absolutely uniform joint on top and bottom.

The specifications of the compressor are as follows:

Engine — 5 h.p., hopper water cooled.
Compressor — $4\frac{1}{2}$ by 6 in., air cooled.
Capacity — 23 cu. ft. free air per minute.
Size of air tank — 20 by 60 in. or 30 by 60 in.
Total weight — With 20-in. tank, 1 650 lb.; with 30-in. tank, 1 800 lb.
Total length — 6 ft.
Total width — 34 in.
Pneumatic tool capacity — With 20 by 60-in. tank, 1 pneumatic calking tool or 1 pneumatic rock drill; with 30 by 60 in. tank, 2 pneumatic calking tools or 1 rock drill.

The cost of the outfit is $436.60 complete, with a calking hammer for calking pipe, cutting or chipping bricks or concrete, and a set of 6 steels and air hose in 50-ft. lengths. We bought an Imperial air hammer for rock drill work for $60.

In conclusion, I would state that we are firmly of the opinion that the air compressor for calking lead joints and for rock drilling has passed the experimental stage in water-works construction, and I would heartily recommend it to any superintendent or engineer for this sort of work.

DISCUSSION.

Mr. William C. Lounsbury. I would like to ask the speaker whether he found it necessary to obtain old calkers or not, or whether he found he could employ cheaper labor.

Mr. Higgins. You can employ cheaper labor. It is perfectly satisfactory, and makes a considerable saving.

Mr. Lounsbury. Will you tell me the type of hammer that you used? You spoke of making some modification of the hammer you first had. Did you have to use a special head?

Mr. Higgins. No. The principle of the head is the same, only we changed the length of the tool. The tools that we bought were long, and the calker discovered that it was much better where they were short, and we simply cut the tools in two and made two of them. In case of the 6-in. pipe, we narrowed down the tool a little.

We did not use the tool for putting in yarn, as we found it was cheaper to tuck it in by hand.

LOW CONSUMPTION OF WATER IN THE TOWN OF MILTON.

BY DAVID A. HEFFERNAN, SUPERINTENDENT OF WATER WORKS, MILTON, MASS.

[*Read September 11, 1914.*]

Milton is a town with a population of 8 470, lying between Quincy and Boston, and bordering on Canton and Hyde Park. It is supplied with water by the Metropolitan system, with two distinct services. The first, designated as the Southern High Service, accommodates about 83 per cent. of the consumers with a daily consumption of 285 000 gal., and has a pressure range of 30 to 110 lb. The remaining 17 per cent. is supplied by the Southern Extra High Service, with a daily consumption of 39 000 gal. and a pressure range of 50 to 133 lb.

On hearing this subject, the natural question is, "How does Milton maintain its low consumption of water, using as it does only 39 gal. per day per capita?"

To my mind, there are three principal reasons, which I will endeavor to explain from a practical viewpoint:

1. Universal meter system.
2. Our method of construction.
3. Rigorous control of hydrants.

Nothing else contributes quite so much to low consumption as a system universally metered. In Milton this is carried out to the highest degree. Not only are the private services metered, but in every municipal building, every standpipe, and every fountain, the water is being measured. Only hydrants escape this minute inspection.

No meter remains on a service for more than five consecutive years. At the end of that time, perhaps before, it is removed, cleaned, repaired, and tested in our own shop.

Meters are read twice every quarter by the inspectors, who carry aquaphones, always on the alert for foreign noises. If the

reading is larger than the average for that house, or a sound is heard which might possibly be a leak in the service pipe, a report is made to the office at the inspector's return.

Then a department plumber is sent to inspect the premises. Should he find the leak to be on the pressure side of the meter, it is repaired immediately by the department at the expense of the owner. If the leak is discovered on the house side of the meter, the owner is notified and his own plumber makes the necessary repairs. In this manner water department and consumer unite in reducing water waste to a minimum.

Another important reason is that the department does all its own work, main construction, services, and repairs.

Our system consists of 49 miles of cast-iron pipe, ranging in size from 4 in. to 16 in., the system being controlled by 576 stop gates; 364 hydrants take care of the fire needs, while the watering-carts may be supplied from 58 standpipes.

1 678 services furnish the inhabitants with water. Our own employees lay the service pipe at a stated cost per running foot, and it extends to the inside of the cellar wall where the meter is set. The responsibility of the department ceases at the meter, which is supplied up to $\frac{3}{4}$ in. without cost to the consumer. Should the applicant for water desire to lay the service pipe himself, or otherwise than by the town, the department will make the tap, and lay the pipe to a point just inside the property line, build a manhole, set the meter, and let him complete the service. However, this choice is very rarely taken advantage of, for the reason that if a leak should occur between the meter and the house, the department would have nothing to do with its repairing. And it has been found that contractors do not use the care in laying the pipe that the department does. Thus, the town, having complete jurisdiction over all the work it does, and over none other, and using only the best materials in this work, is in a better position to prevent unnecessary waste through these channels.

All construction, service and main work is tested by water pressure before back-filling. On all 2-in. work and over, a testing plug, tapped to hold a shut-off, is inserted in the bell end of the pipe. By means of this tap in the plug, the trench may be puddled after it is seen that all joints are tight.

Hydrants used in the town are post hydrants of one type, and are uniform throughout, having a 5-in. gate opening and a 7-in. barrel. Gates on all hydrant branches save shutting down an entire section when repairs on one hydrant are needed. Only firemen are allowed to use hydrants, and then only in case of fire. If contractors need water in a place where no means of supply other than a hydrant is available, the department will send a man to furnish them with water, the contractor paying for the water used and the labor incurred in supplying it. Besides an annual inspection, hydrants are carefully examined after every fire to make certain there is no leakage.

I have tried to explain what makes our consumption so low, as simply and concisely as possible. Many will say, or, at least, think, that it is because Milton does not contain many factories. To refute this argument I have but to give a few figures:

The night consumption tends to bear out my statement. Here, too, the consumption is the lowest of any in the system. An average of only 10 gal. per capita is measured daily, between the hours of 1 and 4 A.M. Compare this with the average of 56 gal. for the district and you will see that our system is in good condition.

The total amount of water measured by the Metropolitan meters in Milton, for the year 1913, was 118 million gal. The registration by house meters was 96 million gal., showing a difference of 22 million gal., or 18 per cent. This is accounted for by flushing dead ends, water used at fires, and the under-registry of house meters. We are fast connecting up our dead ends, and, taking everything into consideration, Milton seems to be in a fair way to lower its already low consumption, of which its water department is so justly proud.

DISCUSSION.

VICE-PRESIDENT SULLIVAN. Mr. Heffernan has just read a paper to us that has shown us what is possible. Of course, we have all been striving to reduce the per capita consumption, and he has achieved remarkable results.

MR. W. A. HAWLEY. The percentage of water unaccounted

for which Mr. Hefferman gives as 18 per cent. is within a fraction of one per cent. of what we have on our plant at Wilkinsburg. We account for 82 per cent. of the water. That, however, is not making any allowance for water loss from leakage or the quantity of water used in washing the streets and flushing sewers taken from the hydrants, and that sort of thing. Our per capita consumption, domestic, based on the water actually measured by the meters, for the past year was between 23 and 24 gal. per capita. Including manufacturing uses, our per capita use is something less than 100 gal.

THE USE OF THE MAGNETIC DIPPING NEEDLE IN LOCATING SERVICE AND GATE BOXES.

BY EDWARD D. ELDREDGE, SUPERINTENDENT OF ONSET WATER COMPANY, ONSET, MASS.

[*Read September 11, 1914.*]

Many of our members are familiar with the use of the dip compass for finding hidden service and gate boxes. For those who have not yet made use of that convenient instrument, I will say a few words with reference to its value to the water-works superintendent. In new water systems, in our small but growing towns, there is frequent necessity of laying pipes in streets and private ways where the grade is not established, the boundary lines are crude or imperfect, and where later there may be considerable change as improvements are made and sidewalks constructed. Houses are often built in advance of such improvements, water supply is furnished, and the records of stop-box locations are not wholly satisfactory or the ties of gate boxes reliable. When a sidewalk is made, the grade is often raised a few inches, or low spots are leveled up, and unless the water-works man is at hand, or notified, the service box is subject to being buried, particularly if it were not in sight at the beginning of such work. Later, when it may become necessary to use such a box, it is of great assistance to be able to locate it exactly, particularly if the ground is frozen. This is the function of the dip compass, or "detector," which can be used with most satisfactory success when the box is covered not over 6 in. or 7 in., which will include most all cases.

The dip compass consists of a magnetized needle or pointer, mounted on a horizontal axis and free to revolve in a vertical plane, normally that of the magnetic meridian. The needle is accurately balanced for the latitude of the locality in which it is to be used, so it will assume a horizontal position when

held in a north and south line, and subject only to the earth's magnetic attraction.

A service or gate box is a sufficiently large mass to offer a strong attraction to the needle, particularly as they are set in a vertical position, which is the most favorable. If the detector is held as described, with the needle at rest on the north and south line, and moved carefully, to avoid oscillation, over the ground and as close as possible to it without touching, when within six or seven inches in any direction from the hidden stop box, the needle will begin to show a deflection or dip, and by following it up to the point of greatest dip, the exact location of the box is discovered. As magnetism, unlike electricity, is not insulated by any substance, the attraction is ever present through air, frozen earth, cement, stone, tar, or anything liable to be encountered.

In a case where a cement sidewalk five or six inches thick was laid over a stop box, the box was located exactly, although the deflection is not so decided and quickly recognized in such a case as when a lesser covering exists. The same process, of course, applies to the ordinary iron gate boxes in street mains, which, in some of our unfinished streets, are often covered three or four inches.

DISCUSSION.

Mr. Lewis M. Bancroft. Mr. President, I had a little experience in the use of this dipping needle. There was one occasion where a tar concrete sidewalk had been laid, covering up the service box; the needle indicated the location of the box. When we came to get through, we found it thirteen inches from the top of the concrete sidewalk to the top of the box. More recently we had an experience trying to find a box where a great amount of rubbish had been dumped over the box, which had been put in before the sidewalk had been graded. First we found a jack-knife; next we found an iron wedge about six inches long and perhaps an inch and a half square, and finally the box. We had another experience with a stone approximately eight inches long, four or five inches wide, and possibly three inches in depth. One end of that stone was magnetic enough to attract that needle. The other end of the stone would repel it.

Mr. J. M. Diven. Mr. Chairman, we located a valve box which covered 14 in., which seems to be about the limit. I have been able to locate in one instance a curb box through a concrete sidewalk. I also had the experience of locating buried horseshoes, etc. At the same time it did save a heap of digging.

If the needle becomes demagnetized, it can be quickly remagnetized, and at slight cost. The speaker had trouble of this kind with his dipping needle compass, which was caused by hanging the instrument on a gas pipe. The constant contact with the iron sapped the magnetism from the needle. Since discovery of the cause of the trouble, the compass has been kept in a wooden drawer, protected from the influence of all iron, and no further trouble has been experienced.

Mr. Herbert E. Bryant. I would like to ask if, in the judgment of Mr. Eldredge, the fact of indicator being kept in a pumping station run with electric power would affect the reliability of the instrument. Something has happened to mine, putting it out of commission, within a month!

Mr. Eldredge. I should say, if a needle was subjected to magnetic influence, its polarity might be neutralized or possibly reversed. I think it should be kept away from any strong magnetic influence, the same as a compass.

Mr. C. D. Sharpe. Mr. President, I have had some experience with the dip needle, and I find, to make the operation of that instrument of the most value, a pipe-finding machine should be used in connection with it. This will give you the line of the pipe, and then it is very easy to trace along that line and find your curb box without digging up tin cans and horseshoes and other things that have been mentioned.

Of course the pipe-finding apparatus costs quite a little, but any of you gentlemen that have used one I think will acknowledge that it will pay for itself, as time goes by. Of course, in cities like Boston and Worcester, where the grade is established and streets paved, you do not have that trouble, but in the country, even if you make very careful measurements, when you lay a service, or put in a curb box, as has been said, if the superintendent is not notified of change of grades, when he goes out to find the curb box again it is gone. The surroundings have

been changed and you are lost. You are in a place where you never were before. But with the pipe-finding machine and the dip needle you cannot go astray.

Just a few days ago I had occasion to dig up a service pipe, and, by the way, it was at my own house, and I had lost it. I was completely astray. It seems that the measurement as given was the total, and then the total was subdivided some other way. I don't know just how it came, but it was nowhere near where the pipe was. I was so sure that the pipe was where it was not that I dug first without putting the pipe-finding machine on to it, and when I discovered it was not there, I went to the office and got the machine and I located it exactly.

Mr. Charles H. Tuttle. We have had very good success in finding curb boxes with an ordinary compass. Perhaps the compass is not as strong as the detector, but we find it a very convenient thing to carry in the pocket. All our men carry a compass. We are also very careful to take angle measurements of corporation cocks on the main as well as service boxes. We try to get measurements from some permanent corner. If it is near the corner of a street, we usually get it from the curb line; if not, we get it from the corner of a house. By taking an angle and using a tape line, we usually locate them pretty quickly.

CARE OF GATES AND HYDRANTS.

BY PATRICK GEAR, SUPERINTENDENT OF WATER WORKS, HOLYOKE, MASS.

[*Read September 10, 1914.*]

Among the important things for a water department to consider — probably the most important to the superintendent — is the matter of gates, hydrants, and meters. The hydrants must always be in working condition for the fire department, since any loss of time in putting water on a fire at its start, due to defective or frozen hydrants, may be attended with serious results.

In our city we have an index card for each of our 700 hydrants, giving the location, make, date set, size, cost, repairs, and date of repairs. We allow no one except a member of the fire department to operate them. We have a man attend all fires day or night, to see that the hydrants are working all right and to render such assistance as he can should there be any trouble with them. After the fire is over he is required to inspect them and see that they are properly closed, and to file a report of the same on cards furnished him. We do not allow any other city department to operate the hydrant in any way for any purpose. Our employees attend to all the opening of hydrants for street or sewer flushing and for puddling, and we charge them only for the water they use. We charge contractors and builders one dollar a day for opening and shutting hydrants, in addition to the cost of water. To plumbers for flushing sewers, etc., we furnish a man and hose and charge $1.50 for his time and water.

About twice a year we flush all our mains by opening the hydrants, and any trouble experienced in any hydrant is reported and rectified. Besides this, our hydrant inspector makes a general inspection of all the hydrants each spring and fall and reports the condition of each hydrant as he finds it. For his convenience we have divided the city into four zones and furnished him with a loose-leaf card book.

During the winter special attention is paid to such hydrants as experience has proven are most apt to give trouble. The inspector takes with him a string to which a piece of lead is attached, which he drops into the hydrant to find out if there is any ice there. So that the string may not get caught in the barrel of the hydrant, he has an eye turned in a piece of wire which he puts into the nozzle and his lead drops without any trouble. In ordinary winters we have no trouble, but in severe ones an occasional hydrant may freeze. If our inspector finds ice in the barrel he thaws it out with hot water; if he finds water he pumps it out with a small hand pump he carries for that purpose, and then puts in salt to keep it from freezing. Knowing the depth of each hydrant, he opens certain ones which may not be deeply set, to see if the branch leading from the main is frozen. Should it prove to be frozen, we take out a 25 h.p. steam boiler, connect it with about 25 ft. of hose to a $\frac{3}{4}$-in. pipe, put steam down through the ground to the frozen pipes in holes two or three feet apart, until the ground is warm enough to thaw out the pipes.

Where our hydrants are set in wet ground, we plug the drip and pump the water out after the hydrant is used.

Whether it is good luck or good care that accounts for it, we never yet had a hydrant frozen when opened for a fire.

About every five years or so we paint our hydrants a bright red and the top a white bronze.

Where the operating nut and stuffing-box are not brass, the lubricating and packing should be carefully attended to, and we send an extra man with our inspector to do this, as he is not able to do it alone. Most of our trouble comes from the hydrants of older makes; there has been some improvement made in hydrants in the last twenty-five or thirty years, but there is room for more.

The importance of good gates is, I think, very fully realized by us all. They control the flow of water to the hydrant, to the meter, and to each of the various fixtures which from time to time have to be repaired or replaced. They ought therefore to be of the best material and of the best workmanship.

If you have to shut off water for any reason and your gates are not tight, you are in trouble; you have to go back another

block to shut off. If your gate leaks at the stuffing-box, you have to dig up the street to pack it; if you have a gate that closes so hard that you break the spindle, you have to dig it up and repair it, and after you clean out the rust and put in your spindle your gate is all right and practically as good as new; therefore I suggest that a gate would be longer free from rust and dirt and could be more easily taken apart and cleaned if it was constructed with a brass gland; brass-lined stuffing-box; top of gate brass lined where the shoulder of the spindle rests; brass bolts and nuts in the stuffing-box, and slotted for easy removal; the rings in the body to be set out one-half inch or more and have a space of one inch on the sides and two inches on the bottom, to keep the dirt away from the gate and rings. A gate so made ought to cost but little more than those at present on the market.

DISCUSSION.

The President. We have listened to a remarkably interesting paper and I want to hear a lively discussion on it.

Mr. J. M. Diven. Mr. President, Mr. Gear spoke of using salt in hydrants to prevent freezing. What was the effect of that on the valve or the valve casing?

Mr. Gear. The salt is placed in the hydrant temporarily, to hold over during the winter months. Salt has no effect on brass, nor on rubber, especially when the gate is shut. We have a few hydrants which give us trouble of this kind, and when the frost comes out of the ground, we repair them.

Mr. Diven. The gentleman also spoke of thawing hydrants by steam. He said he had no more trouble with one so treated during the winter. I should think the hydrant would be more apt to freeze on account of the moisture and steam. I don't understand the theory of that.

Mr. Gear. Mr. President, we have had this machine for a number of years, and use it on service pipes and hydrant branches that are frozen. If a pipe was broken, or any cause required the digging up of the street, where this machine was used, you will find that the soil will remain warm for a week or more. Any pipe that was thawed out by this machine will not freeze for the remainder of the winter.

MR. DIVEN. The speaker can hardly understand the theory that ground thawed out by steam remains warm. One would think that the moisture from the condensed steam would cause it to freeze quickly, and harder than before. We all know that water that has been hot freezes more quickly than water of a naturally low temperature. The speaker had some trouble with some hydrant laterals, on an exposed situation, in the winter of 1903–04. They were frequently thawed by electricity, but almost immediately froze again. They were finally dug, using steam to thaw the ground, and packed with fresh horse manure. Comparatively warm water, that is, water much warmer than that taken from the ordinary taps, was drawn from the hydrant during the winter. The speaker has been informed that these hydrants have given no trouble since, the heat of the manure evidently lasting.

This question of digging up the valve to repack leads one to reflect whether it would not be best, on well-paved and important streets, to place the valves in brick, concrete, or cast-iron pits large enough to permit packing the valves. The first cost would be high, but future expenses and much annoyance would be saved.

When, on the first shut down, valves were found to leak, on account of mud or rubbish under the gates, it has been the speaker's practice to open one or more fire hydrants, or a flush valve, if available, in the district to be shut off, and partly open the leaking valve. By opening partly and closing a few times, the valve can usually be made tight. The rush of water at high velocity through the small opening washes the dirt from the seat ring.

The speaker can hardly agree with Mr. Gear in the matter of testing valves; they should be thoroughly and frequently tested, even to completely closing them where practicable. In no other way can one be sure that they will be tight when needed. With a nearby fire hydrant open, the aquaphone, water sonoscope, or similar instrument will tell if a closed valve on a line is tight. The speaker was put in charge of a water works that had neglected valve tests, and, on making an inspection and test of valves, found 244 out of about 1 100 in some way defective, needing packing, cleaning of boxes, and in many cases with broken stems, — any-

way, not in condition to give service if called upon. How long the valves had gone without testing, the speaker cannot say, but the condition found was certainly serious.

Mr. Gear. Mr. President, we have our men go around and try all valves, put the key on same, partly open and shut them, and if they should find any valve leaking, repair it. If the stuffing-box was properly constructed, there would not be any of this trouble caused from opening and closing of valve, or the leaking of same at the spindle.

Mr. Wm. C. Lounsbury. Do you use the same packing you buy with the valve, or do you take that out and repack it?

Mr. Gear. The packing sent with the valve is as good as any that can be bought. If it is not good packing, then let us insist upon them getting the very best there is, and may be this would overcome the replacing of the packing.

Mr. Lounsbury. We have found it advisable to remove the packing that goes with the gate and put into the stuffing-box carefully prepared packing which we lubricate ourselves.

I would like to ask how often in winter you inspect fire hydrants in regard to freezing, — whether you make a daily inspection or not in cold weather.

Mr. Gear. Knowing the hydrants which cause us the most trouble in the winter time, we make a daily inspection of them. If our inspector should find them all right to-day, he may skip to-morrow's inspection, but you may rest assured that he will keep close tabs on them. I want to say that up in our city we all die on the job, because no one ever resigns or is discharged, so you see that we ought to know the pedigree of every hydrant.

Mr. Lounsbury. I represent Superior, Wis., and unless somebody contradicts me I am going to claim the long-distance record. I came 1 505 miles to this meeting. We have a somewhat colder climate than they used to have here in Boston. I understand now from experience last winter that you are trying to take the record away from Northern Wisconsin. But we have seen more than 40 below, and it is often 30 below. Of course we pay particular attention to freezing, and we have a record which is like Mr. Gear's; it may be either through good inspection or through pot luck, but we have never had a hydrant frozen when the

department wanted to use it, although we have had a great many hydrants frozen which the inspectors have found. Now we find it is necessary to keep a crew of three men through the winter working on the hydrants, testing them, in much the same manner as was told, with a lead sinker on the end of a cord. The hydrants which we find frozen are those which the contractors and others beside the fire and water departments have used during the year.

Now, about salt. We represent in Superior the Water Company; the Gas Company is the same corporation, and I might say that I also represent a private corporation. When the gas services freeze, the common practice is to pump wood alcohol into the service. It clears it out. Now you all know, I presume, that alcohol is good to keep the radiators of automobiles from freezing, and if they do freeze, instead of having ice that expands and breaks the radiator, it makes a kind of mush. When we find a frozen hydrant, we thaw it out with our steam boiler and then give it a good liberal dose of alcohol. We put in a pint or sometimes a quart of wood or denatured alcohol. We use wood alcohol because we have found it a little more efficient. Slush may form around the valve, but nevertheless you are able to turn the stem and open the valve. I think that where you can use it, alcohol is very much better than salt.

The matter of having the contractors and the other city departments use hydrants is a matter of very great importance to water-works superintendents. It is a matter which we have found in the Middle West very hard to control. Particularly in a rapidly growing new city there is a great deal of contract work to be done. A great deal of street paving must be put in, and it seems to be a hardship on the contractors to make them use house services for their work. As it does not seem feasible for the water department to furnish a man to stay with the hydrant, we require all contractors to take a meter from our meter department, making a deposit of \$25, which is returned to him when he returns the meter, and after our inspector has seen that the hydrant is in good shape. That gives us some hold on the contractor. In addition to that, we bill him for water at the regular rates, but the actual amount of water used on such work is so

small that the price we get for the water is immaterial. The reason we want the meter there is to have some hold upon the contractor. The fire chief objects to the indiscriminate use of the hydrants, and has reported to the commissioners annually that the contractors should not be allowed to use the fire hydrants. But it seems to be at least the line of least resistance to permit them to continue to use them.

Then, again, there is the matter of the street watering. I do not know what the Eastern practice is, but in some of the cities valves have been tried on the hose connection of the hydrant, but that does not always work well. We have a great many leaking hydrants because somebody that drives the watering-cart starts to open the hydrant by turning it the wrong way, or does not know when he gets it open.

The matter of sewer flushing causes us a good deal of friction. There, again, it seems that we must permit the head of the sewer department or the sewer foreman to open the hydrants. This is a matter that causes us a great deal of annoyance because Superior has a direct pumping system. When the hydrant is opened suddenly on such a system it may cause a considerable amount of inconvenience. We try to control this by having the foreman call up the station before he opens up a hydrant. We have had our crew out looking for a break or leak only to find the next day that they had two hydrants opened at once and were using water pretty liberally through fire hose with no proper nozzles.

I presume this matter of the alcohol is more or less familiar to you and I would be pleased to know whether that is a common practice through the country or something which is a local condition with us.

MR. JOHN DOYLE. I have been much interested in the paper read by Mr. Gear, as we in Worcester pay especial attention to the care of our hydrants. In the first place, both the street, sewer, and forestry departments are generally permitted to have the privilege of opening all hydrants for construction purposes, the forestry department particularly for spraying purposes. Now we have a form of permit which is issued to all those different departments which they are supposed to return to the water

commissioner within twenty-four hours of the time a hydrant has been opened. We immediately have a man sent out and inspect such hydrants, his time being charged up to the department using them. Now, as you all know, hydrants under such conditions are opened by men who have had no experience whatsoever in opening hydrants. Sometimes you will see a foreman working on a construction job. And often he will send the rawest laborer he has got at work to open the hydrant, and we have to give them further attention. Now, if the inspector finds there is anything the matter with the hydrant, we immediately fix that and charge the cost up to the department which caused it. We employ two men doing nothing else but looking after hydrants. We have about 2 300 fire hydrants that belong to the city, and 234 to individuals and corporations, which we do not attend to unless called upon, and then any repairs are charged up to the individual.

In cold weather, particularly along about the latter part of October or the first of November, we send out and make a preliminary inspection of all the hydrants. As soon as the weather becomes very cold, — possibly along about the middle of December, sometimes earlier, — we start our winter inspection. We have the city divided into five districts and each district divided into four routes, with the exception of District No. 1, comprising the center of the city, which has a total of about 225 hydrants, and is divided into two routes. District No. 1 is covered every other day by one man. The other routes, being on the outlying districts, further away, are covered by two men to each route, covering each district once in four days. Those men carry an iron kettle and a water pail. Sometimes there is salt in the water pail. They work in close touch with one another so that if they should happen to find anything the matter with a hydrant, holding water or skimmed over with a little ice, they go to the nearest house and borrow a kettle of hot water, and if they can overcome the trouble, all right. If the hydrant does not drain, they immediately notify the shop and we send out men to take care of the hydrant. We make a close inspection of all hydrants after a fire.

Now there are eleven men doing nothing else in the winter time

but inspecting hydrants, and those men are generally men whom we employ during the summer months with other work. We have to keep them anyway, and we find that winter employment for them.

As to the method of keeping hydrants from freezing, we have used salt and are now using denatured alcohol with great success, and I find good results from it.

As to the care of water gates and valves, during the winter months we inspect all valves and shut-offs. The men employed on that work are also men whom we employ steadily during the winter months and with other work in the summer time. We have the city divided into districts and routes, and a record is kept of all inspection on a card system. I might also add that for hydrant inspection we have a card system with the inspector's name, the date of inspection, and the condition in which the hydrant was found. We partially close and open all gate valves and see that they are in working condition, and that the boxes are cleaned.

MR. THEODORE MCKENZIE. I would like to ask Mr. Gear how he manages the firemen opening and closing hydrants for purposes of trying the hydrants and throwing fire streams, whether for pleasure, profit, or necessity. I have been troubled a great deal by firemen going out at any time, night or day, summer or winter, and opening hydrants for trial purposes and stirring the water all up. You can't open a hydrant anywhere without getting bad water, and then you have got to go over the whole system to clean it up.

MR. GEAR. We do not have any trouble with the firemen, and they notify us whenever any hydrants are to be opened for trial purposes. Our inspector is there at all times to see that the hydrants are shut down properly, and if he finds any out of order, he files a report to the superintendent.

I heartily agree with Mr. Lounsbury when he says that alcohol is very useful for hydrants.

MR. C. DWIGHT SHARPE. These gentlemen, who have spoken on the care of gates and hydrants, fortunately belong to cities large enough to allow keeping a gang all the time. I happen to represent a small water works in Putnam, Conn., where the

superintendent is the captain and the crew and boatswain's mate, — and the cook stays in the house where I live. If we had men at liberty or where we could call upon them to do these several things that these gentlemen have said, we could be out of some of our troubles, but unfortunately, the superintendent is called upon to do most of these things, and sometimes in the middle of the night, after being tired, he does not wake up when the fire bells ring and he does not get there.

I am very tender about trying to tell a country fireman how he should open a hydrant, because you fellows that belong in the country, where they have volunteer firemen, know that if you get in bad with the firemen you might as well throw up your job. We do have trouble with our firemen in opening hydrants, and even when some city departments have visited us and our hydrants happened to open the other way, they were bound they should open the same way theirs did, and they put the force to it and consequently put the hydrant out of business. If any one present can tell me a way to get ordinary intelligence into a country fireman about opening a hydrant, I would like the receipt.

In our hydrants, the stuffing-box and gland and spindle are all brass, so we have no trouble with the turning of them ordinarily. A short time ago we had a serious fire about two o'clock in the afternoon with the thermometer six degrees below zero, and at two o'clock the next morning the fire didn't seem to be put out thoroughly, and we had another alarm and the same hydrants had to be used again, and they couldn't open one of them. The hydrant was dry, but the stuffing in the gland had frozen on to the spindle, and we couldn't open it until we brought a blow-torch and warmed it up. That came back on the superintendent, of course, because he was the man who ought to have seen that they were right, and stayed out there with a blow-torch all night.

Now as to the packing for gates and hydrants, I have found very good success with a spindle packing made up with some grease and plumbago. I have had no trouble with it whatever and it holds very nicely. I have had trouble with the flax packing coming out.

The matter of hydrants freezing has been mentioned here, and a gentleman beside me said that where ground was frozen and

thawed out it would freeze all the quicker. Now, that has not been my experience. I have always found that where we have had trouble with our service or with hydrant branches, the fall before has been a very dry one, and if we can get the ground full of water late in the fall, we will have no trouble. I do not know how you can explain it, but I explain it in this way, that the moisture in the ground eats up the frost or keeps it from going down so low. I know it has been my experience that with dry ground, frost will go deeper than with wet ground. That may be new to some of you, but I found it so many times.

In regard to the use of hydrants by contractors, of course this could not be done as I have done it, in a large city, I suppose, but where contractors have wanted to use water for building purposes or road purposes it has been my plan to turn the water on to the main hydrant and then put a cap on with the proper valve so that they can control that valve, instead of opening and closing the hydrant every time they wanted to use it.

Mr. Lounsbury. Do you leave that on over-night?

Mr. Sharpe. Yes; of course, as I say, it is a country town, and the firemen would find out that the water was on, immediately they put the wrench on the cap to take it off, and it would take only an instant to close it. Three turns and the valve would open enough to get by the waste.

Our hydrants are the Coffin hydrant with the metal disk and metal valve, and are all leaded on. If any of you have ever tried to repair a hydrant where the seat has been scratched, with the hydrants leaded on, and in positions where you couldn't melt out the joints, you know how difficult it is to face up the seat, and then face the valve to fit it. That is the difficulty that I am in, and while I have had very good success in doing that in the past, I may fail sometime. But it certainly is a task to do it, and it takes nearly half a day to face up a seat and then face the valve to fit it. With bolted flange hydrants it is easy to replace the hydrant and send the injured one to the shop for repairs.

Mr. Gear. In regard to hydrants that freeze after a fire, so that they could not be opened, I would say that they were frozen at the stuffing-box. The same condition is to be found in the old-style hydrant, with iron rod attached and where rust forms in

stuffing-box, even in the summer months. I suggest that you take a hammer, hit the top of the operating rod, and break the frost or rust, whichever it may be: you will readily see that the hydrant can be opened easily.

Mr. Robert S. Weston. I would like to ask if any of the gentlemen have ever used crude glycerine in the hydrants in place of salt or alcohol? It is used a great deal in automobile radiators and in many industrial plants to prevent freezing. It costs about eighty cents a gallon, I think, and will go a great deal farther than alcohol.

Mr. J. M. Diven. I have used it with great success. It doesn't evaporate. It lasts longer.

Mr. W. C. Hawley. I am very glad that municipal plants are beginning to take the position that no one but the water and fire departments should operate the hydrants. I have been up against that proposition for a good many years, and within the last two or three years in making new municipal contracts — I represent a private water company — we have taken the position that the fire hydrants should not be used for any other purpose but fire protection and for street washing and sewer flushing, and then they are to be operated by an employee of the water department. That has been incorporated in our new contracts, and those contracts have been approved by the public service commission of the state of Pennsylvania.

We have one little wrinkle in the testing of our hydrants. We test them three times a year. We have very high pressures, and if we open the hydrant fully and then turn it down again, the street will be flooded or water will be thrown clear across the street. And to obviate that we use a hose valve, put the hose valve on, close it and open the hydrant fully, so as to be sure that it is operating properly; open the hose valve enough to blow out enough water to clean the hydrant. We find that saves the valve a good deal. Otherwise the valve is merely opened, the valve started from the seat, and any foreign matter catches between the seat and the valve, and with some of the hydrants that means repairs. We do not assume all the responsibility for testing the hydrants. We insist on the representative of the municipality — generally the chief of the fire department or someone

assigned by him — going with our assistant and keeping his own record of the test. Then if something happens we have more than the mere word of our own inspector.

As to the care of the valves, I have found that in some mysterious manner valves will get closed. I know of one case where a 16-in. gate had been closed while some repairs were being made, and the foreman took one of his men and started to open that gate and opened it enough so that one man could continue the operation, and left a man to do it. He opened the gate for a while, got tired, sat down and rested, got up, supposed he was opening it, and instead of that closed it. We didn't know that gate was closed until there was a fire. I found on making inspections of a large mileage of pipes a number of gates closed that were supposed to be open. Therefore we have adopted a plan of a report of the foreman or his assistant of every gate that he operates, the reason why it was operated, the time it was closed, and the time it was opened. In that way we try to keep track of just what happens. We make an annual test of all the gates, open them and close them, and in that way we are sometimes surprised to find gates out of order that so far as we knew were all right, with broken stems and other things that would put the gate entirely out of commission if we wanted to use it. We also operate our gates quite frequently in making tests of our distribution system, and that enables us to keep track of the condition of the gates. Under pavements we have been using concrete boxes of pyramidal shape, reinforced concrete slabs put together so that if the valve needs it a man can get down and pack it without digging it up. The boxes are expensive as a matter of first cost, but very much cheaper than having to dig up your valves two or three times.

I should like to ask the gentleman from Wisconsin how much alcohol he uses to a hydrant in order to prevent it from freezing.

Mr. Lounsbury. This alcohol doesn't prevent the water entirely from freezing. It freezes in a kind of mush that does not stick. We put in from a pint to a quart into the barrel. Of course those hydrants are particularly well guarded because if you go back it might test and seem to be free.

Mr. Caleb M. Saville. May I inquire of Mr. Hawley what is the cost of the concrete box that he speaks of?

Mr. Hawley. I can't tell you exactly what the cost is. We have the material at the yard, and it is a rainy-day job for the men. If they have any spare time they make up a few, and the first time we have to repair a valve the box is set. It is a matter of, I suppose, twelve or fifteen dollars.

Mr. Saville. I had rather occasion to look that up a short time ago, and I inquired of the water company in Connecticut that included that pyramidal shape that you speak of. I understood them to tell me that they cost something less than five dollars.

Mr. Hawley. They cost me more than that.

Mr. Saville. These were meter boxes, however, that they put in.

Mr. Hawley. These go out in the street, of course, and require a heavy cast-iron cover.

Mr. Saville. These were a light cover such as would be on the meter box. I imagine the four sides to make the pyramid would be about the same. These that I saw at that time were about two feet wide at the top, perhaps, and perhaps eight feet at the bottom, and beveled so that all four would come together and the box fit on top, about three inches thick, and would cost something about five dollars.

Mr. Daniel A. McCrudden. Mr. President, in Philadelphia they use a concrete box of an elliptical shape, the material for which costs about four and one-half cents, and the labor cost of making them would be four cents an inch in height. We use slabs 4 in., 6 in., and 12 in. high, one on top of the other. The frame and cover costs about \$6.75, the labor in putting in the box and removing the surplus dirt costs about \$4.50, making a total cost of \$13.00 to \$15.00 to replace a wooden box with a permanent concrete box. The cost of repairs is practically nothing.

They are 2 ft. by 2 ft. The top has a 2-ft. circular opening in the elliptical form; it is reinforced with $\frac{1}{2}$-in. iron rods and made to fit our standard frame and cover. This rests right on the elliptical slabs, and the frame and cover, which is 2 ft. inside diameter, rests on the top slab. In this box we can always get to the valve to pack it, no matter how deep; in fact, you can place a valve in the box without digging up by using what we call an

extension sleeve, a casting which I do not think the New England Water Works Association recognizes as a standard casting.

MR. P. R. SANDERS. Mr. President, Mr. Hawley's speaking of finding gates closed mysteriously once in a while reminds me that we have to be very careful on our large 20-in. and 24-in. gates when the men operate them. Of course some of our gates are geared to an upright. They put the key on a small gear and work that awhile. They find it goes easy and they think they have got it about half open. They then will go to work on the big one and turn that in the same way. Instead of opening or closing the gate, they are just shutting it right down again. Just last month we had a large leak, a hydrant blew off from a 10-in. line right on to a 20-in. line; there was about 28 lb. pressure. When we wanted to let the water back again these men went to work on the gate to open it up. They started turning to the right, as we open our gates. It went easy, and they put the key on the center spindle and kept turning the gate the same way. Come to find out, they kept closing the gate down again. If I hadn't been on to it, it would have been closed.

MR. J. M. DIVEN. I was going to say that when hydrant trouble has been neglected, I think it is caused by the use of Stillson wrenches operated by contractors and others. Possibly somebody else has had trouble with that.

THE PRESIDENT. We have suffered greatly.

MR. HERBERT E. BRYANT. I want to ask if there is any demand for such a thing as a faucet seal. I represent Kingston, Mass. There we collect our water tax by fixtures rates in every instance, and we find great difficulty in determining the number of faucets in the house, or any place where they are used, that are in actual use. Some people swear they are not using certain faucets and sill cocks, and in the course of a week or a month you will find they are. Then there are the really honest people that don't use them, that have great difficulty in presenting an argument to assure you that they are not bluffing you. So we have got around that question there by adopting a seal and including in our rules that all faucets that are not sealed shall come under the fixed rate, the water department standing the cost of the seal

and the placing and displacing of the seal. So far we have found, that assists us greatly in the case of vacating tenants. They are very ready to tell us when tenements are vacated, but there have been only one or two instances in which they were in any hurry to tell us about the premises being reoccupied. So it seems that the only thing we could do, to do away with the embarrassments on both sides, was to seal those faucets. Now we have got a very simple device for a seal, and what I really want to find out is if there is any demand for such a thing elsewhere. The first part of seal is nothing but a screw shell that turns on by hand and puts the faucet really out of commission. And the next is a cover, to prevent taking the cap off. This is a copper shell with upward extended lugs, which is turned down over the flange of the faucet, then brought up tight with a wire and seal. Now if there is a requirement for such a thing, I would like to have the different representatives of the water departments leave their names with me or at the desk, and as soon as we get a quantity of them I would be glad to send you a sample and any written instructions that may be necessary. I may state further, that I will leave this on the desk for anybody who cares to look it over.

Mr. Frank J. Gifford (*by letter*). In regard to inspection of hydrants in severe cold weather, I would say that in Fall River we inspect hydrants in the congested value district every day, and in the residential and outlying districts every other day.

In reply to the gentleman from Superior, I would say that I have been using denatured alcohol in hydrants about three years, and find that it gives good satisfaction. Several cases I have in mind where ground water was in the hydrant, and which was treated with alcohol, gave us no trouble during the entire winter.

The alcohol works very well when ground water alone is present, but if a slight leak develops on the valve, the mixture is forced into the head of the hydrant and remains liquid, while the water underneath freezes solid. This condition we find when the cap is removed from the steamer connection, the mixture running out of the hydrant freely.

In speaking of a slight leak developing on the valve, I find that this condition occurs during extremely cold weather; our inspector finds a hydrant perfectly dry when he makes his inspec-

tion; two days after, on the next inspection, he has trouble in taking the cap off. After removing cap, he finds the hydrant solid to the head with ice.

Mention was made of stepping into a nearby house and getting a kettle of hot water to thaw hydrants. This method we used to use until the inspectors began to complain of the nuisance it caused people and of the many refusals they had. Each inspector now carries, beside his pump and hydrant wrench, about half a pail of lumps of quick lime. When he finds a hydrant with ice in, due to ground water, he puts in two or three lumps of lime and perhaps a little cold water, puts on the cap and continues his inspection, returns in about half an hour, and is able to open the hydrant and flush out the lime and pump out the barrel. This hydrant is reported to the shop and is then treated to a dose of alcohol.

ALLOWABLE LEAKAGE FROM WATER MAINS.

BY E. G. BRADBURY, COLUMBUS, OHIO.

[*Read September 9, 1914.*]

It is not the purpose of this paper to discuss at length the miscellaneous losses of water from existing pipe systems, but rather to consider the reasonable standard of workmanship in the laying of new pipe.

Numerous investigations conducted within the past few years have shown enormous losses by leakage and carelessness. The fact that willful waste and defective plumbing are responsible for the major part of such losses, and are, moreover, more easily located and stopped, has resulted in greater attention being paid to them than to the leakage occurring underground, although considerable work has been done in the way of discovering and correcting large breaks.

It is well known that the water unaccounted for in the average system ranges from 20 to 60 per cent., and published records of measured leakage vary from 2 000 to 200 000 gal. per mile of pipe daily. In many of the water-waste survey reports, underground leakage and the losses through unmetered services and sprinkler systems are combined as a single item. The Bureau of Economy and Efficiency in Milwaukee finds that about 23 per cent. of the total pumpage is lost in this manner. The New York reports refer to joint leakage as "relatively small," while showing that underground losses of various kinds reach a very large figure. Mr. Phillips places the underground leakage and willful waste at 57 per cent. of the total amount of water unaccounted for in Chicago. The city of Washington presents the only evidence in the hands of the writer indicative of the relative proportion of main joint leakage, the reports of the engineer department of the District of Columbia containing figures showing that such leakage averages approximately 23 per cent. of the entire amount of water lost beneath the ground surface.

TABLE SHOWING PROPORTION OF MAIN JOINT LEAKAGE DETECTED AT WASHINGTON, D. C., COMPARED WITH TOTAL UNDERGROUND LEAKAGE.

Year.	Total Underground Leakage. Gal. per Day.	From Joints in Mains. Gal. per Day.	Per Cent.
1908	4 243 900	1 013 900	24
1909	6 657 635	1 345 620	20.2
1910	6 364 000	1 034 000	16.2
1911	6 921 916	2 562 461	37.1
1912	5 115 320	746 305	14.6
1913	4 196 070	962 310	23
Average			23

The records of fully metered cities and the results of water-waste surveys prove that, although possible, it is the rare exception when underground leakage is kept down to a low figure. Very few cities keep such loss below 3 000 to 5 000 gal. per mile daily, and many very greatly exceed these figures. Mr. Kuichling, in a paper before the American Society of Civil Engineers (Transactions, Vol. 38), set the familiar standard of one drop per second from each joint, five drops from each hydrant or stop valve, and three drops from each service pipe as a fair average in a well-constructed system, resulting in a total of 2 500 to 3 000 gal. per mile daily.

Main joint leakage is so distributed, except in case of an occasional blow-out, as to make repairs more expensive than can be justified by the saving accomplished, and yet may in the aggregate result in serious losses. This fact imposes on the builder of water lines the duty of exercising every reasonable precaution to insure the tightest possible work. Pipe systems necessarily deteriorate more or less from year to year, but carelessly made joints must be more likely to loosen than thorough and painstaking work, and the ratio of loss between tight and slovenly work will at least not decrease with age.

Statements of leakage in terms of percentage of total water pumped, or gallons per capita, mean very little. The only rational unit is one which takes into consideration length and size of pipe; the writer prefers the number of gallons daily per mile for each inch of diameter, expressed as "gallons daily per inch-

mile." "Gallons daily per foot of lead joint" is an equally rational unit — in fact, slightly more so — but is less convenient, especially if used with exactness. The length of lead joint per inch-mile is about 120 ft.

The practice of applying a test of some character to newly laid pipe is probably general at the present time. This test should preferably be made in the open trench, examining all joints under pressure before covering, but if the pipe is necessarily covered before testing, a maximum allowable leakage per inch-mile should be specified and rigidly enforced.

By the method of open-trench inspection it is possible to make a new system practically bottle-tight. The measured leakage in 5.5 miles of 6 to 12 in. pipe laid and thus tested by the writer at Grandview Heights, a suburb of Columbus, Ohio, amounted to 2.3 gal. per mile daily, or 0.31 gal. per inch-mile. This system is supplied through a meter from the city of Columbus, and every service is metered. The actual amount of water entering the mains in the 2.5 years since its installation was 2 104 000 cu. ft., according to bills rendered. The quantity sold through individual meters for the same period was 1 998 600 cu. ft., and about 30 000 cu. ft. was used in flushing sewer trenches. In addition to this, contractors for several macadam streets were permitted to use water without measurement. Even without making any allowance for this last item, nor for the fact that nearly a mile of extensions have been laid during the period, it will be seen that the water unaccounted for amounts to less than 20 gal. per inch-mile daily.

In the opinion of the writer, the inconvenience to which the public is necessarily subjected by this method of testing is well justified by the certainty of results and the perpetual saving accomplished, except in the busy streets of the downtown district in cities of considerable size. Where the demands of traffic are such that it is absolutely impossible to hold the trenches open, the specified leakage test must be substituted. In designing the extensive improvements to the water works of the city of Akron, Ohio, Mr. F. A. Barbour and the writer specified, after much consideration, a maximum permissible leakage of 200 gal. per inch-mile daily — equivalent to about 1.6 gal. per foot of lead joint.

The pipe laid at Akron comprises new supply lines, lines paralleling and reinforcing old mains of insufficient capacity, and extensions into streets not heretofore furnished with water. The new supply lines and reinforcing mains are laid by contract under the supervision of the designing engineers, Mr. E. A. Kemmler, department engineer, being in immediate charge, while the extensions are laid by employees of the city, under Mr. H. H. Frost, superintendent of water works. All pipe is purchased by contract and is inspected at the foundry by experienced men. The depth of lead specified is $2\frac{1}{4}$ in.

The method used in all tests was as follows: After completion of laying, the pipe was filled with water and usually allowed to stand for about twenty-four hours, to permit the yarn in the joints to become saturated. The pipe having been tapped for a $\frac{3}{4}$-in. connection, a small hand-pump was connected by wrought-iron pipe and fittings, on which a gage was set, the suction being placed in a barrel of water. All gates were then closed and a hydrant valve opened to determine whether gate leakage existed in amount sufficient to flow. The depth of water in the barrel and its diameter at water level were then measured, and pumping begun. If the pressure was readily raised to the required amount, the time was noted and the amount of water required to hold the gage stationary for a period of from ten to thirty minutes carefully observed. The leakage was computed from the quantity so used. If too great difficulty was found in raising the pressure, or if the leakage was found to exceed the allowed quantity, pumping was stopped and the gage observed to see if it would remain stationary after dropping to city pressure, thus indicating gate leakage; if such leakage was not demonstrated, effort was made to find defects in the pipe. In one or two instances pipe which could not be pumped up to pressure on the first trial were successfully tested on the following day, no satisfactory explanation being found. In a considerable number of cases the contractor was required to locate leaks and recalk joints, sometimes causing the reopening of the trench for considerable distances. In two cases cracked pipe was located and removed.

The final results of the tests have been very gratifying. One hundred tests have been made of pipe laid by contract, of which

86 are included in the summary given below. Of the remaining 14, there were 8 in which all joints were visible and no leakage existed, but on account of loss through gates no measurement was made; 3 in which the measured loss somewhat exceeded the specified maximum, but evidence of gate leakage was such as to satisfy the engineers that the specifications were complied with; and 3 in which the leakage was above the specified amount and the work not accepted. Of 40 tests made by the superintendent of water works, of pipe laid by his department employees, 38

TABLE SHOWING SUMMARIZED RESULT OF 86 TESTS OF PIPE LAID BY CONTRACT, AKRON, OHIO.

Size, In.	Length, Ft.	Leakage in Gallons Daily per Inch-Mile.	Number of Tests.
4	717	23	1
6	31 066	66	34
8	6 882	42	6
10	5 123	81	5
12	9 704	102	8
16	8 792	135	11
20	8 389	69	10
24	3 358	69	3
30	14 445	82	8
	88 476 16.76 miles	83.4	86

Pressure from 66 to 152 lb., — 35 lb. greater than static head when improvements are complete.

TABLE SHOWING SUMMARIZED RESULT OF 38 TESTS OF PIPE LAID BY SUPERINTENDENT OF WATER WORKS, AKRON, OHIO.

Size, In.	Length, Ft.	Leakage in Gallons Daily per Inch-Mile.	Number of Tests.
6	37 524	59	32
8	6 509	63	5
10	2 850	133	1
	46 883 8.9 miles	61.7	38

have been tabulated, the remaining 2 exceeding the permissible loss; these are to be dug up if necessary, to locate and repair the leaks.

It is to be noted that all the above figures are probably high, as they include whatever leakage may have occurred through gates as well as actual loss. Such leakage was known to exist in many cases, and in 20 of the tests of pipe laid by contract and included in the above summary every joint was visible and tight, although usually some water was required to keep up the pressure. The amount pumped also covers any contraction or absorption of air contained in the pipe. The presence of any considerable amount of air makes the tests unsatisfactory, and occasionally it becomes necessary to tap the pipe to release it.

Check tests made several months after the original test in two districts of about one mile each, of 24- and 30-in. pipe, verified closely the previous work, showing losses of 55 and 79 gal. per inch-mile respectively.

The results of the Akron tests are considerably below the requirements of many engineers. Mr. W. D. Gerber, in a paper read before the Illinois Water Supply Association in 1913, mentions 167 gal. per inch-mile as the usual allowance. The New York Aqueduct specifications allow 2 gal. per foot of lead joint, equivalent to about 240 gal. per inch-mile. Mr. J. H. Gregory specified permissible leakage at Columbus equivalent to 507 gal. per inch-mile on 20-in. pipe, and 528 gal. on 24- and 30-in. pipe,— all under about 110 lb. pressure, and contributed an article to the *Engineering Record* of April 20, 1912, justifying this specification, with the statement that "the limits of allowable leakage specified were not guessed at, but were determined after a careful study of the measured leakage in pipe lines with which the writer was familiar," and showing that the actual leakage in the pipe laid under these specifications ranged from 71 to 103 per cent. of the amount permitted. This article was in reply to a suggestion contained in a paper read by the writer at the 1912 convention of the Ohio Engineering Society, in which leakage in general was discussed, that Mr. Gregory's specifications "leaned far toward liberality."

Assuming the average diameter of pipe in a complete system to

be 9 in., each 100 gal. daily per inch-mile saved or lost has a value of \$3.28 per year for each mile of pipe at a production cost of \$10 per million gallons, or, capitalized at 7 per cent., is worth \$46.86. Applying these figures to a concrete example, a city of 100 000 population with a production cost of \$25 per million gallons, and 160 miles of mains, would gain \$5 256 per year by a saving of 400 gal. per inch-mile; and, figuring interest and sinking fund at 7 per cent., could afford to have spent \$75 000, or about \$470 per mile, more on construction to accomplish this result, and the same amount lost per inch-mile would cost a city of 200 000 population with 300 miles of mains and a production cost of \$50 per million gal., \$19 700 per year — equal to an investment of \$281 430.

The expense of testing in the manner described is not heavy, averaging about \$50 per mile. Occasionally where careless work has been done and the pipe covered, the contractor foots a rather heavy bill of expense; but the knowledge that the work is to be tested discourages carelessness, and most of the tests are made quickly and without trouble.

The writer believes that the results at Akron are as good as can usually be obtained under practical conditions. Many years ago Mr. C. F. Loweth stated before the American Society of Civil Engineers that he had satisfied himself of the possibility of laying water pipe with a leakage not exceeding 60 to 80 gal. per inch-mile daily. This is borne out by the data given above. It is apparent that to go farther than this in a specification is not safe, on account of gate leakage and other internal conditions.

In view of all the above facts, the writer proposes as a standard for allowable leakage in new cast-iron water pipe an average of 100 gal. daily per mile per inch of diameter for each complete contract or district, with a maximum limit of 200 gal. daily per mile per inch of diameter not to be exceeded in any single test. The recommendation is made, however, that open-trench testing, with all joints visible, be specified, covering being done only by special order, and the allowable leakage clause used only when it is entirely impracticable to keep the ground open.

TABLE I.

Tests of Pipe Laid by Contract, Akron, Ohio.

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day per Inch-Mile.	Remarks.
Turner	663	6	150	128	All joints seen.
Turner	599	6	150	157	All joints seen.
High	661 37 33	20 16 6	136	179	All joints visible.
High	629 40 103	20 16 6	120	55	All joints visible.
High	751 13 15	20 12 6	120	0	
May	1 262	6	120	75	
Yale	1 130 18	6 4	125	56	
Grand	475	6	90	104	All joints visible.
High	824 15 20	20 16 6	128	20	All joints visible.
Thornton	514 17	16 6	120	39	All joints visible.
Iron	478	16	140	80	
E. Market	545 15 6 54	30 24 8 6	122	67	
E. Market	1 867 63	30 6	105	27	
Steese	361 4	16 6	125	59	
Chestnut	365 4	16 6	150	68	
Exchange	949 23	20 6	115	2½	
Exchange	920 19 50 40	20 8 6 4	108	16	
Exchange	1 145 4	20 6	90	162	Trench partly filled.
Exchange	930 60	20 6	105	100	
Exchange	1 037 65	24 6	104	105	
E. Market	1 634 24 41	30 10 6	107	96	
High	393 23 7	20 8 6	132	32	

TABLE I.—*Continued.*

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day per Inch-Mile.	Remarks.
E. Market	1 278 40 35 35	16 12 8 6	115	165	
E. Market	84 1 166 95	30 16 6	85	140	Gate leakage.
E. Market	1 229 40 60 70	16 12 4 6	106	224	Pipe covered.
Case	1 187 48 25	20 6 16	113	84	
Exchange	805 20 41	24 16 6	110	65	8 joints covered.
Spicer	1 488 140	16 6	98	185	
Carroll	638 4 44	16 6 4	96	73	
E. Exchange	1 501 38	24 6	106	46	
Center	1 197	6	130	111	All joints visible.
Center	611	6	135	145	
Park Place	536 7	6 4	132	117	
Amherst	554	6	135	45	
Sibly Al.	435	6	135	189	
Wheeler	124 336	8 6	111	0	All visible.
Wheeler	356	6	110	64	
Wheeler	626	6	140	36	
Poplar	393	6	130	60	
Poplar Huron	1 718	6	133	103	
Newton	2 650	30	91	53	
Main	1 197 18	12 6	150	53	
Yale	727	6	121	40	
Cross	1 171	6	122	75	
Market	374 109 3 3	16 12 8 6	132	129	
West	659	6	128	67	
Andrus	837	6	102	60	
Johns	957	6	115	88	All visible.

TABLE I.—*Continued.*

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day per Inch-Mile.	Remarks.
Cross	448	6	122	40	
Clark	1 463	6	93	65	Visible.
Fountain	761	6	112	44	All visible.
Nash	692	6	115	37	All visible.
Furnace	1 087	6	152	0	One half visible.
Furnace	1 233	6	150	0	
Dixon Pl.	458	4	110	23	
Beaver	1 509	6	104	0	All visible.
Brown	1 489	6	97	11	All visible.
Market	1 725	12	118	142	All visible.
	75	8			
	14	6			
Woodland	385	6	125	0	All visible.
Market	967	12	117	176	All visible.
	97	10			
	50	8			
W. Market	843	12	110	110	
	26	6			
	26	4			
Thornton	942	10	126	56	
	111	6			
Newton	1 811	30	66	149	Covered.
	22	8			
	22	6			
Manchester	567	10	117	0	All visible.
W. Market	1 013	12	105	82	All visible.
	64	6			
Church	455	8	125	61	All visible.
	16	6			
W. Market	980	12	85	66	
	72	6			
State	764	16	116	23	All visible.
	75	8			
Case	1 890	30	130	47	
	57	6			
W. Market	573	12	77	35	
	55	6			
	14	8			
W. Market	2 204	12	118	102	All covered.
	143	6			
	25	8			
Valley	1 106	6	137	139	All vis. Gate leak.
	26	4			
Grant	744	8	113	11	All visible.
	108	6			
Goodwin	573	6	130	91	

TABLE I.—*Concluded.*

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day per Inch-Mile.	Remarks.
Bittman	1 335 64 16	10 6 4	140	158	All visible.
Grant	1 503 38	8 6	106	105	
Grant	995 100	8 6	120	35	
Grant	996 92	8 6	113	18	
Maple	1 184 28	10 6	130	49	All visible.
Maple	967 43	10 6	130	83	All visible.
Thornton	1 774 98	8 6	97	0	
Bowery	658	6	130	25	All visible.
Forge	995	6	102	60	All visible.
Forge	1 000	6	100	102	
Hazel	2 240 72 31 19	30 6 10 8	112	115	14 joints calked later. Gate leakage.
Hazel and Adams	1 724 26 22	30 6 4	104	53	May have included section above. Some valve leakage.

Summary.

Total number of original tests	100
Tests included in summary	86
Tests where all joints were exposed and no leakage exists but gate leakage was bad	8
Tests where joints were covered and gate leakage is known to exist, pipe accepted	3
Tests where pipe has not been accepted	3
	100

TABLE II.

TESTS OF PIPE LAID BY SUPT. OF WATER WORKS, AKRON, OHIO, 1914.

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day per Inch-Mile.	Remarks.
Halsted	641	6	100	19.8	All joints covered.
Union Pl.	924	6	100	0	All joints covered.
Diagonal Rd.	2 850	10	75	133.4	All joints covered.
Crosby	1 363	6	90	15.8	All joints covered.
Ledge	570	6	120	0	All joints covered.
Roswell		6			
McNaughton		6			
Broad	2 437	6	110	90.9	All joints covered.
Ash	630	6	125	14.1	All joints covered.
Wildwood	842	6	90	99.5	All joints covered.
Charles	564	6	150	29.2	All joints covered.
First		6			
Chittenden	2 188	6	100	27.2	All joints covered.
Chittenden	580	6	100	162.0	Leak at V. stem.
Brook	681	6	125	61.4	All joints covered.
Blaine	500	6	125	0	All joints covered.
Dayton	500	8			
Hillier	707	6	125	142.5	All joints covered.
Thayer	1 632	6			
Elma	1 140	6			
Bellows	510	6	115	77.0	All joints covered.
Abel	1 134	6		0	All joints covered.
Commins	406	6	130		
Cole	910	8	110	55.2	All joints covered.
	163	6			
Curtis	700	6	110	0	All joints covered.
Parkdale	853	6	135	14.9	All joints covered.
Euclid	1 033	6	130	12.3	All joints covered.
Euclid	276	6	140	16.3	All joints covered.
	375	8			
Fuller	1 130	6			
Hart	900	6	100	169.4	All joints covered.
Fourth	550	6			
Fifth	550	10			
Howes	680	6	85	0	All joints covered.
Martin	445	6			
Fifth	340	6	80	100.3	All joints covered.
Talbot	1 767	6			
Lacroix	1 750	6	130	36.2	All joints covered.
Bank	789	6	110	16.1	All joints covered.
Euclid	1 076	8	110	170.4	24 unused services.
Silver	646	6	140	177.0	All joints covered.
Summit	1 189	8			
Summit	530	6	110	86.4	All joints covered.
Park	1 800	6			
Camp	600	6	125	56.8	All joints covered.

TABLE II. — *Continued.*

Street.	Length, Ft.	Size, In.	Test Pres. Lb.	Leakage, Gallons per Day, per Inch-Mile.	Remarks.
Fifth..........	1 326	10			
Chittenden....	360	6	105	87.7	All joints covered.
Duane........	940	6			
Hart..........	263	8			
Carpenter.....	748	6			
Edwards.......	303	6	125	141.8	All joints covered.
Shelby........	307	6			
Garfield.......	1 440	8	125	42.0	All joints covered.
	100	6			
Campbell......	750	6	135	84.4	All joints covered.
Buchtel.......	756	8	120	28.9	All joints covered.
Broadway.....	352	6	120	38.6	All joints covered.
Chestnut......	206	6			
Pine Al........	477	6	140	124.8	All joints covered.
Ardmore.......	580	6	75	10.9	All joints covered.

SUMMARY.

Total number of tests made....................................	40
Total number of tests included in summary......................	38

Tests were omitted because leakage exceeded specifications in initial tests. These will be repeated. All joints were covered and no definite reason can be assigned.

DISCUSSION.

THE PRESIDENT. This paper presents many new points which are of great value. I was very much interested in Mr. Bradbury's statement in regard to the importance of testing pipe lines on the second day after putting on pressure, and that he was much more successful with that method of procedure than in testing immediately after filling the line.

MR. CLARENCE GOLDSMITH. I believe that it is highly important to fill the line the day before it is tested, because it is almost impossible in ordinary work, where you are laying pipe fairly level, to avoid getting some high spots in the line, and it is with great difficulty that the air is forced out, particularly if the joints are well driven. About two weeks ago we had an experience of this kind in attempting to get 400 lb. pressure on the high-pressure

line. It was very slow work until we got rid of all the air, for there were several high spots.

But, over and above finding the leakage, I think it is equally as important to have the pressure test before the lines are accepted for use, for it is not an uncommon thing at the time of a fire for lines to rupture and to put the fire department to great disadvantage. I have in mind a city in the South, where some three months ago there was a bad fire, and among a series of accidents which happened on the works was the failure of a 12-in. line which had been laid within a year. If that line had been tested out at the time it was put in, at one and a half times the working pressure, in all probability the defect would have been found.

There is one city which, I think, is a preëminent example. That is Atlanta, Ga., where all the lines laid are tested at 300 lb. before they are filled in. That rule is strictly adhered to. When I first talked to the superintendent, Mr. William Rapp, with regard to this, I was a little skeptical. He was then laying a 20-in. line through the heart of the city, and held every joint of that line open, and subjected it to 300-lb. pressure. That was practically all the inspection he had of the pipe, as they do not have any inspectors at the foundry; but the foundry people understand that for any failure of the pipe they are directly responsible. The pressure was maintained for one hour, and every joint was gone over carefully. Of course there were a few spits of water, but the test showed a very good job indeed, and the superintendent assured me that every pipe in Atlanta is subjected to such a test.

I think the figures that the speaker gave show us very forcibly how much money we can afford to spend to keep a line open, because in many places the extra expense is comparatively small compared with the loss of the benefit which will be obtained by keeping the line open to make the test.

Mr. W. C. Hawley. There is one point in the making of a lead joint which may not be familiar to all, and that is the temperature at which the lead should be calked. I remember some twenty years ago laying a block of pipe in a hurry so that the mayor and council could see the pipe tested. The lead was calked as fast as it was run, and when the water was turned into the pipe you could have taken a shower bath at any of the joints. That

set me to thinking, and I found that the coefficient of expansion of lead is about three times that of cast iron. After that I always specified that the lead should not be calked until it was cold; and I have found a great difference in the tightness of the joints when that specification has been followed.

Incidentally, on the matter of testing pipe in the open trench, I have found that the use of leadite is very convenient, because we can test 100 or 200 ft. of pipe whenever we want to by putting in a plug and then we can cut the leadite out quickly and go ahead and lay pipe. I have done that in thickly populated districts where we couldn't leave a long length of trench open.

Mr. Frank L. Fuller. I should like to ask Mr. Bradbury if in making the test before the back-filling was done he used a temporary plug, and if so, how the air was gotten rid of.

Mr. Bradbury. We never used any temporary plugs in making the tests, on account of the interference with the progress of the work and the additional water to get rid of in the trench when the plug is removed. The general rule in the Akron tests has been to keep the trench open throughout. We have had a good deal of trouble and many complaints, but usually the people have been willing to see that it was really for their benefit that the trench should be left open, and that they should suffer a little temporary inconvenience, really very little in most cases, rather than to have leaky pipes.

The figures which I have quoted indicate plainly that a city can well afford to use a great many more gates than is customary and still be money ahead, if by so doing it can get a tight pipe line. If the difficulty in testing the pipe in the open trench is the inconvenience to the public, and it won't stand for having the trench left open, the use of more gates will largely overcome the objection. In the example which I cited, a city of 100 000 population, producing water at a cost of $25 per million gallons, can afford to spend $470 per mile of pipe to save 400 gal. per inch-mile, using a seven per cent. capitalization. It is hard to get too many gates in a pipe system, and this advantage is to be considered.

In connection with the tabulations of the Akron tests, I wish to say that in case of pipe laid by contract, it was the rule throughout that most of the joints were exposed, as covering was only done

where for some reason it was absolutely impossible to keep the trench open. I think there were not more than twenty where the entire pipe was covered. The pipe laid by city labor was covered before testing.

Mr. Allen Hazen. I understand that in Los Angeles all of the joints in the cast-iron pipe system are made with Portland cement and sand mortar and that it is believed in Los Angeles that the joints so made are fully as tight as could be made with lead, and they are also much cheaper and more convenient to make in the trench.

In San Francisco, the works are owned by the Spring Valley Water Company, and in one important respect the joint differs from those of the standard pipe of the New England Water Works Association and of the American Water Works Association. The difference is in the shape of the groove in the bell. The design as used was made by Mr. Herman Schusler, then chief and now consulting engineer of the company, who had previously had experience with pipes at extremely high pressures in Nevada mining camps.

In the Schusler joint the groove is reversed, so that the face nearest the end of the pipe has only a slant of one in three, while the face away from the end of the pipe slants nearly one to one. It is believed in San Francisco that it is easier to calk this joint tight, and that it stays tighter, especially when there is movement in the joint.

Mr. Schusler explained to me that it was his idea that with the flat slope toward the end the effect of calking is to expand the lead to completely fill the groove, while with the abrupt slope toward the end the effect of hard calking is to compress the lead in the cylindrical space between the end and the groove, and afterward to push the mass away from the face of the abrupt slope of the groove, leaving an opening which made the joint less solid and gave an opportunity for movement or leakage. A great many joints of actual pipes have been sawed at San Francisco to demonstrate the character of the joint and the position of the lead after calking.

Some old French works indicate that French pipe of twenty years and more ago was cast with a groove something like that in the San Francisco pipe, while Fanning's "Water-Supply Engineer-

ing," which best represents American practice of a generation ago, shows a groove with about equal slopes on both sides. Turneaure and Russell show the grooves used in several American cities some years ago, and these indicate bells in use in Chicago, Brooklyn, Providence, and St. Louis, with more or less flat slopes toward the outer end. On the other hand, the Boston pipe and the pipe of the Metropolitan Water Works had the abrupt slope toward the outer end, and this is the type that has been adopted by the standard specifications of the two associations.

In dimensions, the San Francisco groove does not differ very much from the New England standard. The peculiarity is that it is reversed.

It would be interesting if Mr. Brackett, or some one, could tell us about the Boston practice, and why the groove has its abrupt part toward the end of the bell, and why that was adopted in place of what now appears to have been the older practice.

Mr. Goldsmith. With regard to the joint as adopted by Mr. Schusler, of the Spring Valley Water Company, and the modification of that joint as adopted by the city of San Francisco and also by the city of Boston for high-pressure mains, I will say that before that joint was developed and adopted the city of San Francisco made a very exhaustive study of the shape of the grooves in the bell; and in order to determine the effect of the driving of the lead on joints of different designs, they cast a number of hubs which were split and had ears on either side, held together by bolts, and joints of different depths were poured. Then the bell could be removed without disturbing the lead, so that one could see plainly what the effect of driving was. The joint with the New England Water Works groove reversed is practically filled by good hard driving, whereas the joint of the New England or American Water Works Association is not completely filled. And I think when you consider the thing from a practical standpoint the reason is very simple. If you have a hole that you want to tamp full of sand, the more acute the angle is, the easier the sand can be tamped into the hole. And so with lead. The lead will drive back very much more easily. The tests of the joints which were designed for the first high-pressure mains showed that even the first groove would not fill with the hardest driving. The

Boston water-works high-pressure joint consists of an outer joint with the groove reversed, and an inner one with the groove in the same position as in the American and New England Water Works joint.*

The particular reason why San Francisco went into this question was on account of the effect of earthquakes on cast-iron pipe. Having adopted cast iron as the material, they wanted to be able to lay the pipes in the area which was affected by earthquakes. For although a large portion of the city lies on the rock backbone of the peninsula, yet there are a number of old sloughs which have been filled in and now form a part of the central portion of the city near the waterfront, and when an earthquake occurs, these act exactly as a bowl of jelly, and the water pipes are pulled apart or telescoped. The pipe laid in these districts is all spigot pipe, connected by sleeves with, I believe, four inches between the ends of the pipe, and that is covered over by either a sheet of tin or copper. When an earthquake occurs, the telescopic effect occurs at that point, and the pipe simply slips into the sleeve; or if it is drawn apart, it simply pulls out. The experiments were all conducted on a line of 8-in. pipe. They put the pipe together, and after the line was made up they pulled it apart with a total movement of 2 in. They did that twelve times, and between intervals they measured the leakage, and at the end of the twelfth time the leakage of the joint was practically nothing. In other words, the joint is self-tightening.

In connection with the use of a plug, in the construction of the San Francisco system, they developed a plug which could be inserted into the barrel of the pipe, designed on the principle of an elevator plunger. Instead of using leather, their mechanical engineer used rubber, and the entire end-thrust of this plug was taken by the blocking put behind it, thus saving the pipe from any end strain whatever. When the test was over the blocking was simply knocked out and the plug was easily removed. I have a number of those plugs which we are going to use in Boston.

Mr. Hazen. Do I understand that the Schusler groove is filled solid?

Mr. Goldsmith. In our tests we have burst the bell, and the

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* Journal N. E. W. W. A., *28*, 113.

outer groove is filled solid. You can see the mark. When the bell is first broken it is very easy to be seen by the eye. After the lead has been out a little while you cannot tell, but just after it is broken you can tell.

Mr. Hazen. Why wouldn't it be a good idea to reverse the groove in the standard specifications, then?

Mr. Goldsmith. I don't know but it would.

Mr. Alfred D. Flinn. I would like, Mr. President, to ask the writer, In the standard allowance for leakage in the joints, what pressure in the main is supposed to exist, — both in the test and in general?

Mr. Bradbury. It is based on a water level 85 ft. above the height of the distributing reservoir at low water; that is, about 35 lb. more than the static head. Our experience in regard to the relation between a given pressure and defects in the joint is not very illuminating. I have not been able to find much, if any, difference with pressures up to 175 or 200 lb. In fact, I have had some cases where the same pipe leaked less under 180 or 190 lb. than it did under 100 lb. I have not yet found the explanation of that phenomenon, but I know it occurred. I believe that in any specification for ordinary service pipe — I am not now speaking of high-pressure fire lines — for any pressure up to, say, 150 lb., it is not necessary to make any difference in the specified permissible leakage on account of variation in test pressure.

Mr. Flinn. A little experience we have had in an experimental way in connection with flexible joints may suggest a possible explanation of the difference in leakage in pipe lines in some instances. In making some experiments on 36-in. flexible joints we found that under pressure the joints were tighter, and on examining the joints it was observed that there was a considerable area on the spigot end of the pipe which was exposed to unbalanced pressure, thus tending to force the spigot out of the bell; in other words, producing a compression on the lead joint by pulling the pipe, as is done in some submarine lines, and forcing the lead more tightly against the surface of the spherical bell. A similar action might occur with straight bell joints under some conditions.

The specification of two gallons leakage allowed per foot of

joint in the specifications, of which the writer spoke, was for pipe lines under a pressure of about 130 lb. per sq. in. static, with a special allowance for water ram beyond that. In one contract for 48-in. pipe under that specification the contractor had much trouble in meeting the specification. The trouble originated by his doing unsatisfactory work to begin with; but after he was required to go over practically all of his joints, in some cases at the expense of digging them up, he did meet the requirements of the specifications.

In connection with the pipe line across the Narrows of New York Harbor, which is now under construction, some very interesting experiments have been made with lead joints for flexible, or spherical, jointed pipes 36 in. in diameter. First, an endeavor was made to find an alloy which, if cast into such joints, would have no shrinkage, or possibly a very slight enlargement of the metal on cooling. We found no alloy of any practical value in that line. Indeed, we did not succeed in finding any which did not have at least a little shrinkage, so that idea was given up as impractical, and the practice which we have adopted of forcing cold lead into the joint has been followed. The bell and spigot are of the type known as the Duane joint, modified. The bells are not only turned accurately, but are finished by grinding, so as to give the inside a smooth and truly spherical surface. The lead is cast in the joint space in the usual way, and then additional lead is forced, cold, into the shrinkage space by means of gib screws, through thirty-two holes in the bell, arranged in two rows of sixteen each, staggered. The lead is applied in the form of pellets, $\frac{9}{16}$-in. in diameter and $1\frac{3}{4}$ in. in length. Three pellets are forced into each of the back holes. About 20 to 22 lb. of lead are thus added to a 36-in. joint to fill up the appreciable space due to shrinkage of the lead as it cools. Joints made in this way, after several deflections of about 5 degrees in each direction, under hydrostatic test at 100 lb. pressure per sq. in., are so tight that a leak of only a drop of water will occur in the space of a minute; and some joints are absolutely tight. A mixture of lubricating grease with 10 per cent. of graphite is applied to the holes to aid flexibility of the joint. Work on this pipe line has only been begun, so that the degree of tightness of the 10 000-ft. line as a

whole cannot be told until at least a year from the present time.

I would like to inquire whether in any of the pipe lines mentioned in the paper, lead wool was used.

Mr. Bradbury. None whatever — nothing but lead.

Mr. Flinn. We have used lead wool in some few difficult places with considerable advantage. In testing the effect of calking a joint, in one case we found that using a pneumatic hammer, having a pressure of probably about 60 lb. at the tool, the effect of calking was not observable beyond about five eighths to three quarters of an inch from the face of the joint, when the tool was handled by an experienced and unusually careful man.

A Member. I would like to inquire of the writer of the paper if, speaking of filling the line the day before he made the test, whether he ever had any trouble on account of shifting of any of the bends. I have had two experiences, both of them pretty near the pump, on a 16-in. main, where I have filled the pipe, not for the purpose of making a test, on one day and have been called up before the next morning.

Mr. Bradbury. In the village of Grandview Heights, which is referred to in the paper, we had one bend which was blown out three times before we got it so it would stay. In the Akron work there has been a little trouble of that kind occasionally. This suggests a question which I would like to ask Mr. Goldsmith, with regard to the putting in of these temporary plugs. He spoke of bracing against the bank. We tried that in the case of one gate to be laid on rather a steep grade, so that the pressure at the bottom was necessarily rather high, and we found that nothing we could use in the way of bracing would hold the gate from pushing off. It was a 24-in. gate on a 30-in. line, and we found it would push the whole end of the trench away when the pressure was put on.

Mr. Goldsmith. The advantage of the plugs is that they are put so far into the pipe that they can stand a pull-back of about a foot easily before they will come out; and if you have a moderately stiff soil and put a wedge in, or, rather, two wedges with their ends against the back of the trench, and have a third wedge coming between them so as to distribute part of your load on the

sides of the trench as well as the rear, up to sizes we have, that is, 20 in., we have no trouble at all. We had a contractor the other day who braced a 16-in. gate with a 2-in. plank across a masonry wall. There was no alloy in that joint; the joint was on a straight line and there was no call for it. I think you will have no difficulty in holding the plug if the man who is doing the work realizes what he has to hold.

MR. EDWARD D. ELDREDGE. I consider that it is of the greatest importance to give attention to the foundation of the pipe. Even if the pipe is all right when tested in the open trench, it is not certain that after the back-fill is put in it will not start to such an extent as to cause a leakage. I think that is a point which is often overlooked.

THE PRESIDENT. Our specifications say one-half gallon per linear foot of joint per twenty-four hours under 400 lb. pressure maintained for one hour. The critical part of that hour, so far as the contractor is concerned, is the last twenty minutes. His fate is decided then. We have not done much of it yet, two or three tests only, but have come easily within the requirements.

MR. FLINN. That is with your new type of joint?

THE PRESIDENT. Yes.

MR. DEXTER BRACKETT. I can add little if anything to what has been so well stated by the speaker, relative to leakage from water pipes. In my experience in connection with the Boston and Metropolitan supplies, I have found leakage from the mains generally within the limits given by the speaker, and I have frequently experienced difficulty in accurately determining the leakage on account of the presence of air in the pipes. The following figures give the results of leakage tests made from

Inside Diameter of Pipe in Inches.	Sum of Lengths Tested		Average Leakage Found per Lin. Ft. of Pipe in Gallons per 24 Hrs.	Average. Leakage per Lin. Ft. of Lead Joint in Gallons per 24 Hrs.
	Feet.	Miles.		
48	116 563	22.0	3.7	3.16
42	11 744	2.2	2.5	2.43
36	25 663	4.9	2.9	3.19
30	7 287	1.4	0.6	0.81
24	20 553	3.9	2.1	3.44
20	40 231	7.6	3.6	7.00
16	49 903	9.4	1.9	4.65

fifteen to twenty years ago of mains connected with the Metropolitan Water Works, tests being made soon after the pipes were laid.

The total length of the different sizes tested was 271 944 ft., and the average leakage per linear foot of lead joint per twenty-four hours was 3 gal.

Where pipes are laid in public streets it is seldom feasible to allow the pipes to remain uncovered for a sufficient length of time to allow them to be tested before the trenches are refilled.

I will ask Mr. Goldsmith to answer the question relative to the best form of joint to be used to secure water-tightness, because I believe that the city of Boston has made a number of very valuable experiments upon the form of joint, and as a result of these experiments I think they are now using joints containing a double groove. The same or a similar form of joint has been adopted for a pipe line on the Metropolitan Works where special care is being taken to secure water-tightness.

Referring to the form of groove used in the sockets of pipes on the Metropolitan Water Works, the lead grooves used on the Boston Water Works previous to 1891 were in the form of a semicircle of $\frac{1}{4}$-in. radius, having its nearer edge placed one inch from the face of the bell.

Grooves of this design in the pipes furnished by the foundries generally took the form of an irregular depression rather than a sharp-edged circular groove, and in 1891 the form of groove was changed to the triangular form now used in Boston, and which has also been adopted by the Metropolitan Water Works and by the New England and American Water Works associations.

So far as I know, no particular thought was given to the angle made by the sides of the groove, and it is possible that the form used in San Francisco, with the short side facing the joint opening, is preferable to that adopted by the New England Water Works Association.

For pressures in excess of 100 lb., grooves in both the bell and spigot of the pipe will doubtless give a more satisfactory joint than any form of a single groove.

Regarding the effect of variation in temperature on the tightness of joints, I agree with a previous speaker that joints which

are tight when the pipes are first laid may leak a few months later if temperature changes have occurred in the mean time. On the Metropolitan Works several lines of pipe crossing rivers were laid with pipes having smooth spigot ends with a slight taper. When these pipes contract with falling temperature the joints open and cause leakage.

PROCEEDINGS.

The Thirty-Third Annual Convention.

Boston, Mass.,
September 9, 10, 11, 1914.

The Thirty-Third Annual Convention of the New England Water Works Association was held at the Copley-Plaza Hotel, Boston, Mass., September 9, 10, and 11, 1914.

The following members and guests were present:

Members.

G. H. Abbott, S. A. Agnew, J. M. Anderson, W. G. Aubrey, M. N. Baker, C. H. Baldwin, A. F. Ballou, L. M. Bancroft, F. A. Barbour, H. K. Barrows, C. H. Bartlett, G. W. Batchelder, G. A. Benjamin, F. D. Berry, C. R. Bettes, F. E. Bisbee, A. E. Blackmer, E. M. Blake, C. A. Bogardus, George Bowers, C. L. Bowker, Dexter Brackett, E. C. Brooks, E. G. Bradley, H. E. Bryant, James Burnie, W. H. Butler, J. S. Buzby, T. J. Carmody, C. J. Callahan, J. T. Carmody, L. W. F. Carstein, E. J. Chadbourne, J. C. Chase, R. C. P. Coggeshall, M. F. Collins, H. S. Clark, F. L. Cole, F. L. Clapp, W. T. Clark, R. L. Cochran, W. R. Conard, J. E. Conley, H. R. Cooper, G. E. Crowell, F. L. Cushing, Gorham Dana, F. A. Darling, J. J. Corkery, C. E. Davis, J. C. DeMello, Jr., J. M. Diven, A. O. Doane, John Doyle, L. R. Dunn, E. R. Dyer, H. P. Eddy, E. D. Eldredge, G. C. Emerson, G. F. Evans, E. E. Farnham, B. R. Felton, J. N. Ferguson, G. H. Finneran, A. D. Flinn, R. J. Flynn, J. H. Flynn, F. F. Forbes, F. L. Fuller, Patrick Gear, H. T. Gidley, F. J. Gifford, T. C. Gleason, A. S. Glover, W. S. Garde, Clarence Goldsmith, J. M. Goodell, F. W. Gow, J. W. Graham, F. W. Green, F. H. Gunther, R. A. Hale, R. K. Hale, F. E. Hall, E. A. W. Hammatt, L. M. Hastings, W. C. Hawley, A. F. Hart, Allen Hazen, D. A. Heffernan, F. C. Hersey, Jr., D. J. Higgins, I. G. Hoagland, J. L. Howard, C. S. Howe, A. C. Howes, C. L. Howes, H. C. Jenks, C. E. Johnson, G. A. Johnson, W. S. Johnson, G. R. Jones, J. W. Kay, F. T. Kemble, Willard Kent, J. A. Kienle, Patrick Kieran, J. W. Killam, S. E. Killam, F. C. Kimball, A. C. King, G. A. King, J. J. Kirkpatrick, Morris Knowles, C. F. Knowlton, H. O. Lacount, E. S. Larned, W. F. Learned, M. B. Litch, E. J. Lonergan, E. J. Looney, W. C. Lounsbury, P. J. Lucey, D. B. McCarthy, D. A. McCrudden, F. A. McInnes, T. H. McKenzie, Thomas McKenzie, J. N. McKernan, Hugh McLean, J. A. McMurry, F. A. Marston, A. E. Martin, T. B. Martin, W. B. R. Mason, W. E. Maybury, John Mayo, J. H. Mendell, W. H. Merchant, Jr., F. E. Mer-

rill, G. F. Merrill, Leonard Metcalf, H. A. Miller, F. F. Moore, J. W. Moran, William Naylor, Henry Newhall, A. E. O'Neil, E. L. Peene, T. A. Peirce, J. H. Perkins, H. E. Perry, A. E. Pickup, R. W. Pratt, W. H. C. Ramsey, A. A. Reimer, J. L. Rice, E. W. Quinn, L. C. Robinson, B. M. Rockwood, Ransom Rowe, D. S. Rundlett, G. A. Sampson, G. A. Sanborn, R. P. Sanders, C. M. Saville, A. L. Sawyer, W. P. Schwabe, C. D. Sharpe, J. E. Sheldon, Carlton Scott, C. W. Sherman, E. C. Sherman, H. L. Sherman, M. A. Sinclair, C. H. Smith, J. W. Smith, Sidney Smith, G. H. Snell, H. T. Sparks, E. W. Smith, G. Z. Smith, J. F. Sprenkel, G. T. Staples, R. H. Stearns, E. L. Stone, T. V. Sullivan, W. F. Sullivan, H. A. Symonds, C. J. Sweeney, G. A. Stowers, F. O. Stevens, R. L. Tarr, C. N. Taylor, L. D. Thorpe, J. A. Tilden, A. H. Tillson, E. J. Titcomb, D. N. Tower, G. W. Travis, C. H. Tuttle, W. H. Vaughn, William Volkhardt, Ernest Wadsworth, J. H. Walsh, Percy Warren, R. S. Weston, W. J. Wetherbee, G. C. Whipple, J. C. Whitney, L. J. Wilber, F. B. Wilkins, W. H. Wilson, F. I. Winslow, G. E. Winslow, F. J. Wise, I. S. Wood and L. C. Wright. — 218.

Associates.

Addressograph Co., by A. R. Hitchcock, A. L. Davis, H. C. Delaney, H. B. Phillips, Miss Molly Kowalsky, A. H. Williams, C. B. Kuisnere, and C. H. Swift; Allen & Reed, Inc., by Z. M. Jenks; American Bitumastic Enamels Co., by L. B. Darling; James Boyd & Bro., by L. Lebengood; Builders Iron Foundry Co., by G. H. Lewis, B. B. Bartlett, F. N. Connet, A. B. Coulters, and D. J. Purdie; A. M. Byers Co., by W. W. Weller, J. J. Riley, A. M. McCormack, and H. F. Fiske; Central Foundry Co., by R. W. Conrow; Chapman Valve Mfg. Co., by H. H. Cook, F. J. Radley, H. U. Storrs, W. B. Atkinson, J. J. Hartigan, J. F. Mulgrew, C. E. Pratt, V. N. Bengle, and H. M. Tupper; Darling Pump & Mfg. Co., by H. A. Synder; Dixon Crucible Co., by G. W. Hart, J. W. Gledhill, and H. A. Nealley; Eddy Valve Co., by H. A. Holmes; Electro Bleaching Gas Co., by E. D. Kingsley; *Engineering News*, by F. B. Godley and H. R. Annes; *Engineering Record*, by R. K. Tomlin, Jr., Burdette Phillips, and I. S. Holbrook; Fairbanks Company, by C. H. White and A. W. Farwell; Goulds Mfg. Co., by R. E. Hall; Hays Mfg. Co., by C. E. Mueller and F. F. Myers; Hersey Mfg. Co., by W. T. Kershaw, S. B. Greene, George McKinnon, W. A. Hersey, L. S. Barnard, and H. D. Winton; Kennedy Valve Company, by M. J. Brosnan; Johnson-Washburn Co., by J. V. E. Johnson; Leadite Company, by George McKay, J. P. McKay, and C. A. Vance; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Mfg. Co., by A. R. Taylor and G. A. Miller; Mueller Mfg. Co., by G. A. Caldwell, W. N. Fairfield, and F. B. Mueller; Multiplex Mfg. Co., by J. F. Casey; *Municipal Journal*, by S. W. Hume; MacBee Cement-Lined Pipe Co., by J. D. MacBride; National Meter Company, by J. G. Lufkin and H. L. Weston: National Tube Company, by H. T. Miller and J. E. Fleming; National Water Main Cleaning Co., by Clinton Eglee and B. B. Hodgman; Neptune Meter Co., by H. H. Kinsey,

R. K. Blanchard, and T. D. Faulks; New York Continental Jewell Filtration Co., by R. E. Milligan; Norwood Engineering Co., by R. B. Weir and H. W. Hosford; Pitometer Company, by E. D. Case; Pittsburgh Meter Co., by J. W. Turner and V. E. Arnold; Platt Iron Works Co., by J. H. Hayes and John Sturgess; Rensselaer Valve Company, by F. S. Bates and C. L. Brown; Ross Valve Mfg. Co., by William Ross; S. E. T. Valve & Hydrant Co., by C. L. Lincoln; A. P. Smith Mfg. Co., by T. F. Halpin, F. L. Northrop, and D. F. O'Brien; Standard Cast Iron Pipe & Foundry Co., by J. H. Blanchard and W. F. Woodburn; W. P. Taylor Company, by P. J. Weigel; Thomson Meter Co., by E. M. Shedd, J. L. Atwell, and S. D. Higley; Union Water Meter Company, by E. K. Otis; United States Cast Iron Pipe & Foundry Co., by D. B. Stokes; Ware Coupling & Nipple Co., by C. K. Hyde and A. E. Milner; Water Works Equipment Co., by W. H. Van Winkle, E. T. Scott, and W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons and C. R. Wood; Henry Worthington, by A. M. Pierce, W. T. Bird, Samuel Harrison, E. P. Howard, R. L. Littenger, G. P. Aborn, W. D. Ford, E. B. Allen, and F. H. Hayes. — 115

Guests.

Maine: Augusta, Wesley W. Albee; Castine, G. A. Benjamin; Lewiston, Mr. and Mrs. T. W. Kerrigan; Portland, George B. Sydleman. *New Hampshire:* Henniker, Mr. E. N. Cogswell; Nashua, Mrs. W. F. Sullivan. *Massachusetts:* Allston, Mrs. A. W. Farwell; Andover, Charles Bowman, Mrs. F. L. Cole; Arlington, Mrs. H. S. Clark, Mr. and Mrs. J. E. Minor, Robert E. Whittle; Auburndale, Mrs. Helen H. Sisk; Belmont, Mrs. C. W. Sherman, Mrs. H. L. Sherman, Mrs. E. C. Sherman, Richard W. Sherman; Boston, Mrs. H. H. Kinsey, Mrs. A. S. Glover, Mrs. G. A. Caldwell, Mrs. A. R. Taylor, Mrs. J. M. Hanlon, Mrs. A. O. Doane, Miss M. J. Cooley, Mrs. A. M. McCormack, Mrs. J. E. Cobb, Mrs. W. F. Woodburn, Mrs. F. I. Winslow, Mrs. C. F. Knowlton, Mrs. E. E. Martin, Miss A. MacDougall, Harriett Sammons, Mrs. J. A. Tilden, Lou Sanders, Mrs. H. P. White, Mr. and Mrs. J. F. Charnock, C. F. Glavin, Mrs. E. M. Shedd, Miss J. M. Ham, Mrs. E. C. Fisher, Mrs. William Wright, Mary E. Flynn, Mrs. G. C. Emerson, William E. Whittaker, Mrs. G. H. Finneran, S. M. Spencer, Mrs. Dexter Brackett, E. O. Teague, Floyd Kinsey, Ellen Kinsey, J. F. Monahan, L. H. Klugel, T. A. Moul, E. H. Milliken, Mrs. C. E. Kelly, Miss Helen Shea, Edward W. Howe, Mrs. W. H. Williams, G. H. Finnerty, Miss H. E. Howes, Francis C. Hersey, W. T. Linehan, M. J. Horrigan, B. T. Rogers, James Tilden, Jr., Lester W. Tilden, Frederic H. Fay, Harry S. Wright, Mrs. E. Milner, Miss Annie L. Lufkin, J. E. Carthy, E. H. Blume; Braintree, Mrs. W. E. Maybury; Bridgewater, Mrs. John Mayo; Brockton, Mrs. L. J. Wilber; Brookline, G. H. Francis, M.D.; Cambridge, Mrs. G. C. Whipple, Mrs. L. M. Hastings, J. H. Ripley, S. T. Barker, Howard S. Knowlton, Mrs. F. H. Hayes, James J. Scully, Dr. S. H. Osborn; Chicopee, Mrs. C. A. Bogardus; Cohasset, Mrs. D. N. Tower, Miss B. L. Tower; Danvers, Mr. and Mrs. A. W. Beckford,

Mrs. Henry Newhall; Dedham, Mrs. G. T. Staples, Miss G. M. Staples, Miss F. S. Staples, Miss S. K. Staples; Dorchester, Francis McInnes, Miss E. G. Knapp, Harriett E. Jordan, Miss Winifred Swallow, H. M. Tupper, H. Wing; Dracut, Mrs. F. H. Gunther; Duxbury, Miss Abbie J. Freeman, Everett, Mr. and Mrs. L. P. Sawin; Fall River, Mrs. Patrick Kieran, Mrs. F. J. Gifford; Gardner, F. W. Dinwiddie; Haverhill, Marshall G. Richey, F. C. Driscoll; Holyoke, Mrs. T. J. Carmody, Mrs. Hugh McLean, Miss Alice Doran, Leo Bacon; Lawrence, Mrs. A. A. Whitman, Mr. and Mrs. A. H. Marsden; Leominster, Mrs. W. J. Wetherbee: Lowell, Mr. and Mrs. J. H. Carmichael, Miss K. Carmichael, George W. Thomas, James D. Carmichael, Mrs. R. J. Thomas, Louisa C. Thomas; Malden, Mr. and Mrs. J. W. Murphy, J. D. Diver, Miss Annie Diver; Medford, Miss Gow, Mrs. F. C. Coffin, Mrs. L. D. Thorpe, Mrs. J. H. Hayes, Henry F. Hughes; Melrose, Mrs. E. C. Brooks, Mrs. J. L. Howard, Miss F. A. Hunton, D. C. Albee; Middleboro, John J. Pearson; Milford, Mrs. J. W. Kay, Mrs. R. F. Kay, Roland F. Kay; Nantucket, A. E. Smith; Natick, G. Fred Whitney; Newton, Mrs. B. R. Delton, Mrs. H. P. Eddy, Mrs. A. W. Robinson, Miss Anna I. Miller; Norwood, Mrs. H. H. Cook, George A. Smith, Mrs. J. E. Conley; Onset, Mrs. E. D. Eldredge, Miss Grace Eldredge, Miss Hastings; Plymouth, Mrs. A. E. Blackmer; Quincy, Miss Lorna M. Weston; Needham, Rodney S. Adams, Joseph C. Lounsbury; Reading, Mrs. E. J. Chadbourne, Harry A. Bancroft; Roslindale, Mrs. Paul Lounsbury, Miss M. E. Lounsbury; Saugus, Mrs. A. F. Hart; Somerville, Mrs. H. G. Blake, Mrs. Samuel Harrison, R. D. Hildred, Mrs. S. E. Killam, Mrs. D. L. Dow, Mrs. F. E. Merrill, C. R. Hildred, Russell H. Spaulding; Springfield, Mrs. W. N. Fairfield, F. R. Lovell, Mrs. A. E. Martin, Mrs. C. A. Kilbourn, Mrs. A. B. Fairfield, B. L. Walsh; Taunton, Joseph F. Welch, D. J. Mahoney; Wakefield, Miss E. Tousley, Mrs. W. H. Butler; Waltham, Mrs. G. E. Winslow, Miss Myra Winslow, Mrs. D. J. Higgins; Ware, Charles M. Hyde, Mr. and Mrs. C. W. Booth, Miss Elsie LeGate; Watertown, Mrs. A. E. O'Neil, Mrs. M. F. Barker, Edward F. Hughes; Wellesley, Mrs. H. D. Winton, Mrs. C. N. Taylor, Mrs. W. A. Hersey, Mrs. F. C. Hersey, Jr., Mrs. F. L. Fuller; West Roxbury, M. A. Flynn, Mrs. H. J. Mahon; Winchester, W. T. Dotten, F. L. Waldmyer, Mrs. H. W. Dotten, Mrs. and Mr. E. H. Rice; Worcester, Mrs. G. W. Batchelder, Mrs. John Doyle, Mrs. E. W. Kerwin, W. H. Larrabee. *Rhode Island:* East Greenwich, Mrs. T. A. Peirce, Mrs. E. A. Vaughan; Providence, Mrs. I. S. Wood, Miss Mary Arnold, Miss Dorothy Chase; Pawtucket, Mrs. H. C. Jenks, F. A. Thomas; Narragansett Pier, Mrs. Willard Kent. *Connecticut:* Hartford, Mrs. C. M. Saville; Plainville, Mrs. J. N. McKernan; Southington, Mrs. T. H. McKenzie. *New York:* Amityville, Mrs. Clinton Inglee; Brooklyn, Mrs. F. A. Smith, C. A. Whitney; Jamaica, L. I., Mrs. C. H. White; New York, Mrs. J. L. Atwell, J. H. Vanburen, L. P. Anderson, A. L. Marsh, Mrs. F. F. Moore, Mrs. B. B. Hodgman, Mrs. R. D. Wertz, I. H. Case, Mrs. J. W. Smith, Thomas E. Irwin. *New Jersey:* Bound Brook, Mrs. W. B. R. Mason; Gloucester, Ernest Grif-

fith; Plainfield, Mrs. J. H. Blanchard, R. H. D. Blanchard; Summit, Mrs. F. C. Kimball; Trenton, Mrs. and Mrs. Alvin W. Bugbee. *Pennsylvania:* Pittsburgh, Mrs. Morris Knowles, Miss Helen Knowles, Maurice Knowles, Jr.; Philadelphia, E. M. Nichols; Steelton, Mrs. W. B. Litch; Wilkinsburg, Mrs. W. C. Hawley. *Washington, D. C.:* Wm. F. Wells, E. B. Rosa. *Wabash, Ind.:* Edwin H. Ford. *Urbana, Ill.:* H. F. Ferguson, Mrs. Wm. Ferguson. *St. Stephen, N. B.:* C. J. McKenzie. *Santiago, D. R.:* John Brown. — 255.

Wednesday, September 9, 1914.

The Convention was called to order shortly after ten o'clock by Mr. Frank A. McInnes, President, who spoke as follows:

Ladies and Gentlemen of the New England Water Works Association,— It is now my very pleasant duty to declare the thirty-third annual convention of our Association wide open, under pleasant skies and amid beautiful surroundings. A " feast of reason " has been prepared for you, which I am very sure will prove nourishing; the " flow of soul " depends upon each individual member. Keep in mind the prophecy regarding poor Jack, who worked too hard, and let us in our amusement have no " dull boys," but let each of us make sure that all others are having a thoroughly good time. Our badge should be a sufficient introduction. Above all things, let us be certain that the ladies, who have graced this convention with their presence, are remembered every moment.

In the ballroom adjoining, a notable and particularly attractive exhibit is presented by our Associate members; do not forget to visit it, and do not forget to study it, for you will be well repaid by so doing. One word of advice: Please be on time at all functions, for upon your prompt attendance largely depends the success of our convention. I welcome you all.

You are doubtless all aware of the regrettable accident which has prevented the attendance of the governor this morning; I am sure we all wish for him a speedy recovery. It now gives me particular pleasure to introduce the distinguished guest who is with us, under whom it is my privilege to serve. He is giving the city of Boston an administration which promises to be historic, for the reason that he is considering only the best interests of the entire city, and is granting special privileges to none. I have the honor to introduce the Hon. James M. Curley, mayor of Boston. [Applause.]

Mayor James M. Curley. *Mr. Chairman, Ladies and Gentlemen,* — In common with your presiding officer, I desire to express my regret at the inability of his Excellency the Governor and also of the Lieutenant-Governor to be with us to-day, for I realize that the most necessary element in the life of the Commonwealth, or in the life of the nation, is the constructive force such as is represented by the New England Water Works Association.

Your meeting in Boston at this time is of particular interest, not only to me, but it should be to every individual in the entire city. We have neglected in the past to give the proper amount of study and attention to our water-works development, and it is only when some such condition as that represented by the great disaster at Chelsea or at Salem visits the community that we have a proper appreciation of the value of a modern water-works system.

We are endeavoring to meet conditions as they confront us in our own municipality. We differ from European cities, inasmuch as they are very many hundreds of years older than our communities, and the materials of construction are largely what are known as non-combustible, while in our communities structures are largely of wood or other inflammable material. The city of Boston is compelled to pay an excessive insurance rate because of the class of construction that is found in the city. We are at present engaged in the installation of a high-pressure water system that in all probability will represent an outlay on the part of the municipality of not less than $2 000 000. We are carrying out the same policy that is being generally pursued by the communities that are scattered throughout New England, of changing over our water mains; and the probability is that between the high-pressure system and the regular maintenance account, the city of Boston will this year expend in the vicinity of $3 000 000 on water-works proposals direct.

We, of course, rejoice in the fact that we in all probability have, thanks to the president of your organization, and to the efficient corps of gentlemen associated with him, as good a water supply, if not the best, that is to be found in the United States. I sometimes feel that perhaps everybody takes that same view of the water supply in his own country that we in Boston have, that is it is the best, and that suggests to my mind the story of two

travelers on an ocean steamer. One said to the other, "I can tell where a man comes from by simply making a reference to fire departments." The other gentleman said, "Why, that is impossible." "Well," he said, "now there is a gentleman looking over the rail, and I will try it on him." So he walked over to the rail, and standing near the lone passenger said in a voice sufficiently loud for him to hear, "It is rather difficult to say really which city has the best fire department." Immediately the man turned around and said: "Grand Rapids, Mich., small, but very efficient." And so it is with our water supply. We believe that we have the best in the United States, and if in any measure the splendid character of the service that is received by the citizens of Boston can be traced to the President of your Association, then the entire city is obligated to the New England Water Works Association. [Applause.]

We are exceedingly pleased to have you with us, and we appreciate the advantages that accrue to the membership of an organization of this character, and to the public at large, from the interchange of ideas, and from the opportunity to make an inspection of the improvements and the progress that is being made in this particular line of human endeavor. As I looked at the exhibits in the other room, all of them intended to make life better because of you men having lived, it was impossible for me to prevent my mind from recurring to the exhibits on the other side of the ocean at the present time, and I thank God that this nation is at peace. I sincerely trust that the wish of the President of the country, and of every sincere American, may shortly be fulfilled, and that peace and prosperity and progress may come to the people on the other side of the ocean, and that America may have an opportunity to fulfill her mission and be the agent of peace throughout the entire world. [Applause.]

Mr. R. J. Thomas. I call for three cheers for Mayor Curley of Boston. [The members of the Convention rose and gave three cheers.]

Mayor Curley. I thank you very much, gentlemen.

Mr. Allen Hazen. Mr. President, we have known for a long time that the mayor is a close student, but I must say that it is a surprise to me to see how he has mastered one of the fundamental

principles of the water-works business, and how he sees the difference between what has to be done in Boston and in other American cities and that which has to be done in European cities. In Europe the buildings are usually fireproof, and the function of the water works is to distribute water; but here water must be furnished not only for domestic and manufacturing uses, but also to put out fires. That makes a fundamental difference in the whole water-works business, and the $2 000 000 that Boston must spend on the high-pressure system represents only a small part of that difference. But I think we may look forward confidently to the time when our cities also will be fireproof, and when this heavy additional load which is now put upon the water-works systems will be eliminated.

I have had the pleasure of spending some months recently in San Francisco. That city has been rebuilt since the fire, and the business district is now more nearly fireproof than that of any other city on the American continent. If the mayor has not been there, I hope he will have an opportunity to go and see what has been done, for I know that he will appreciate the great advantages in all directions growing out of the fireproof construction.

The members of this Association are always glad to come to Boston, for this is the home of the Association, and we always feel at home here and know that we are always welcome. In behalf of the members, I thank his Honor for his kind words. [Applause.]

The President. Now, gentlemen, we will proceed to business, and I will ask the Secretary what he has for us.

The Secretary. We have applications for membership from the following:

Ernest Wadsworth, Duxbury, Mass., water commissioner; James E. Cowper, Boston, Mass., hydraulic engineer, assistant manager of Runser & Co., Ltd., for past eight years; Horace J. Cook, Waterville, Me., assistant superintendent Kennebec Water District; Thomas C. Sheldon, Fitchburg, Mass., civil engineer and water commissioner; E. Weller Smith, Glens Falls, N. Y., superintendent water works and city engineer; L. W. F. Carstein, Long Beach, N. Y., superintendent of the Long Beach Water Company; Arthur S. Watson, Oak Bluffs, Mass., superintendent water works; Raymond C. Allen, Manchester, Mass.,

civil engineer; Charles S. Clark, Boston, Mass., member of Board of Water Commissioners, Duxbury, Mass.; Charles F. Barker, Rowayton, Conn., secretary of the Tokeneke Water Company; Edward J. Tucker, Cristobal, Canal Zone, in charge of Mt. Hope filtration plant, Panama Canal; George L. Stebbins, Seal Harbor, Me., president Seal Harbor Water Supply Company; Gordon B. Smith, Middletown, Conn., civil engineer; Carleton Scott, Woonsocket, R. I., superintendent of water works; Clifton L. Rice, Lowell, Mass., in charge of experimental work for the purification and extension of the water supply of Lowell; F. L. Clapp, Edgartown, Mass., engineer and superintendent of water works; Edward G. Bradbury, Akron, Ohio, engaged as practicing engineer in connection with water and sewerage works; W. C. Tannatt, Jr., Easthampton, Mass., town engineer and superintendent of public works; John T. Carmody, Hartford, Conn., with the Hartford water works; Walter H. Jackson, Attleboro, Mass., general manager and director of the Seaconnet Park Water Company, at Seaconnet Point, R. I.; Sam C. Waldron, East Providence, R. I., superintendent of Watchemoket Fire District, East Providence, R. I.; Edward W. Quinn, Cambridge, Mass., general superintendent Cambridge water works; John J. Corkery, Norwich, Conn., superintendent water works; Allston F. Hart, Saugus, Mass., superintendent water works; George H. Read, South Egremont, Mass., incorporator and president of the South Egremont Water Company; Walter S. Garde, Hartford, Conn., president Board of Water Commissioners; Rupert W. Wigmore, St. John, N. B., commissioner of water and sewerage; Eugene M. Byington, Boston, Mass., superintendent of construction Boston Fire Department, general hydraulic work and steam fire-engine expert; Frank J. Davis, Ansonia, Conn., superintendent of water company; William Latter, Boothbay Harbor, Me., superintendent water system; Cornelius J. Sweeney, Stoneham, Mass., superintendent of streets, water, and sewers; George H. Sargent, La Grange, Ga., city engineer and superintendent water works; Edward Drake, New Bedford, Mass., civil engineer; J. B. Warriner, Lansford, Pa., chief engineer Lehigh Coal and Navigation Company and superintendent of Panther Valley Water Company; D. H. Townley, Elizabeth, N. J., engineer water company; Clinton S. Howe, West Medway, Mass., chairman water commissioners; George T. Prince, Omaha, Neb., engaged in general water-works engineering; W. G. Aubrey, Hudson Falls, N. Y., manager of Spring Brook Water Company. — 37.

Associate: Ware Coupling and Nipple Company, Ware, Mass.; F. B. Godley, New York, N. Y., business manager *Engineering News; Municipal Journal*, New York, N. Y.; MacBee Cement-

Lined Pipe Company, Boston, Mass.; Columbian Iron Works, Chattanooga, Tenn., manufacturers of fire hydrants, valves, meter and valve boxes, sluice gates and water-works supplies; Multiplex Manufacturing Company, Berwick, Pa., manufacturers of and dealers in water-works supplies; G. Frank Uhler, of A. M. Byers Company, manufacturers of Byers wrought-iron pipe; Addressograph Company, Boston, Mass., office systems; William P. Brew, New York, N. Y., representing Westinghouse Machine Company, steam turbines, gears, pumps, etc.; W. P. Taylor Company, Buffalo, N. Y.; F. W. Shepperd, New York, N. Y., *Fire and Water Engineering.* — 11.

Mr. R. C. P. Coggeshall. I suppose all these names have been before the Executive Committee and are all properly endorsed?

The President. Yes.

Mr. Coggeshall. Then I move that the Secretary be empowered to cast one vote in favor of the applicants.

The motion was adopted, and, the Secretary having cast the ballot of the Association as directed, the candidates named were declared elected members of the Association.

The President. The next business on the program is the report of the Committee on Standard Specifications for Cast-Iron Pipe. I am the chairman of that committee, and I am sorry to say that the committee is unable to present a final report at this time. Several meetings have been held, and a number of informal conferences, both with a similar committee from the American Water Works Association and with different pipe manufacturers, and substantial progress has been made, but that is as far as we can go with our report to-day.

The next thing in order is the report of the Committee on Statistics of Filter Operations, Mr. George C. Whipple, chairman.

Mr. Whipple stated that the committee was not prepared to present a final report at this time, but had prepared a preliminary report, of which he would read a part. He then gave a summary of what the committee had done, and expressed the hope that they might be ready with the final report at the annual meeting. Mr. Edwin C. Brooks and Mr. Robert S. Weston spoke upon matters suggested by the report of the committee.

Mr. Allen Hazen, chairman of the Committee on Meter Rates,

gave a synopsis of the report of the committee as printed, and said that it was the hope of the committee that the report would be discussed fully, without gloves, and that the committee might be continued and given an opportunity to make its final report. After remarks by Mr. J. M. Diven, Mr. R. C. P. Coggeshall, Mr. Arthur E. Blackmer, Mr. Arthur A. Reimer, and Mr. George F. Merrill, on motion of Mr. William F. Sullivan it was voted that further discussion of the reports of both the committees on Statistics of Filter Operations and on Meter Rates be postponed until one of the winter meetings, and that meanwhile advance copies of the reports be sent to all of the members, so that an opportunity might be given for written as well as oral discussion.

On motion of Mr. R. C. P. Coggeshall it was voted that the President be authorized to appoint a committee of five to present later in the year, at the proper time, as provided by the constitution, a list of officers to be voted for for the ensuing year. In making the motion Mr. Coggshall said that he wanted it distinctly understood that the maker of the motion was not to serve on the committee.

(Recess till 2 P.M.)

At the afternoon session Mr. Frederic P. Stearns, chairman, presented a synopsis of the report of the Committee on Low Water Yields of Catchment Areas in New England, the full report of the comm'ttee being in print. The report was discussed by Mr. Allen Hazen, Mr. J. M. Diven, Mr. T. H. McKenzie, and Mr. Harold K. Barrows, and on motion of Mr. Hazen it was voted that the report be accepted.

A paper entitled, "The Construction of Dams," by Mr. A. E. Walden, superintendent and chief engineer of the Baltimore County Water and Electric Company, Baltimore, Md., having been submitted in print, was read by title.

(Adjourned to 8 P.M.)

At the opening of the evening session the Secretary read applications for membership, properly endorsed and approved by the Executive Committee, from the following persons:

H. S. Clark, Arlington, Mass., superintendent of public works; T. P. Martin, West Springfield, Mass., superintendent of the water department; W. B. R. Mason, Bound Brook, N. J., super-

intendent water works; George G. Anderson, Denver, Colo., consulting engineer; Herbert E. Bryant, Kingston, Mass., superintendent water department. — 5.

Associate: James J. Hart, Pittsburg, Pa., of Epping-Carpenter Pump Co.; Johnson-Washburn Co., Boston, Mass., pipe fittings. — 2.

On motion of Mr. Edwin C. Brooks the Secretary was directed to cast one ballot in favor of the applicants whose names he had read, and he having done so, the gentlemen were declared duly elected members of the Association.

Mr. E. G. Bradbury, Columbus, Ohio, read a paper entitled, "Allowable Leakage from Water Mains." The paper was discussed by Mr. Clarence Goldsmith, Mr. Dexter Brackett, Mr. W. C. Hawley, Mr. Frank L. Fuller, Mr. Allen Hazen, Mr. Alfred D. Flinn, and Mr. Edward D. Eldredge.

Mr. James A. McMurry, engineer in charge of income branch, water service, Boston, Mass., read a paper entitled, "Metering an Old City." This paper was discussed by Mr. Arthur A. Reimer, Mr. Francis T. Kemble, Mr. Charles W. Sherman, Mr. Daniel A. McCrudden, Mr. John A. Kienle, and Mr. Frank L. Fuller.

(Adjourned to 10 A.M., Thursday, September 10.)

THURSDAY, SEPTEMBER 10, 1914.

At the morning session on Thursday, September 10, Vice-President Sullivan presided, and Mr. Frank A. McInnes, in charge of the Boston Water Department, read a paper prepared by himself and Mr. Clarence Goldsmith, engineer high-pressure fire service, Boston, entitled, "Lessons from the Salem Fire." The paper was discussed by Mr. H. O. Lacount, Mr. Gorham Dana, Dexter Brackett, Mr. Morris Knowles, Mr. W. C. Hawley, Mr. R. C. P. Coggeshall, Mr. T. H. McKenzie, Mr. Walter O. Teague, Mr. Charles W. Sherman, Mr. Charles H. Smith, Mr. J. M. Diven, Mr. Frederic P. Stearns, Mr. Alfred D. Flinn, and Mr. Johnson. The authors of the paper also participated in the discussion, which occupied the entire morning session.

(Adjourned to 2 o'clock P.M.)

The President called the afternoon session to order and intro-

duced Mr. Burdette Phillips, an associate member, who, speaking in behalf of the McGraw Publishing Company, publishers of the *Engineering Record*, explained the company's plans for publishing a directory of water works in the United States and Canada, their reasons for undertaking the work, and the part which the company hoped the Water Works Association would take in the plan.

THE PRESIDENT. Now, gentlemen, we come to a part of our exercises which is very close to my heart, at least. We are going to hear directly from the men who are actually managing the water works and who know better than anybody else can tell them, of their difficulties, and are able to advise and assist the rest of us. I am going first to ask Mr. Forbes if he will kindly tell us what he knows about boiler troubles.

Supt. F. F. Forbes, of Brookline, Mass., read a paper on "House Boiler Troubles." The paper was discussed by Mr. John H. Flynn, Mr. Theodore H. McKenzie, Mr. D. A. Hefferman, Mr. J. Allen Butler, Mr. Edward D. Eldredge, Mr. William Naylor, and Mr. George E. Winslow.

The next paper, by Supt. Daniel J. Higgins, of Waltham, was on "Machine Calking of Lead Joints." The paper was discussed by Mr. William C. Lounsbury and Mr. Percy R. Sanders.

Supt. Patrick Gear, of Holyoke, next read a paper on "Care of Gates and Hydrants." The paper was discussed by Mr. J. M. Diven, Mr. William C. Lounsbury, Mr. John Doyle, Mr. Theodore H. McKenzie, Mr. C. Dwight Sharpe, Mr. Frank E. Merrill, Mr. Robert S. Weston, Mr. J. M. Diven, Mr. W. C. Hawley, Mr. Caleb M. Saville, Mr. Daniel A. McCrudden, Mr. P. R. Sanders, and Mr. Herbert E. Bryant.

Next followed a paper by Supt. William F. Sullivan, on "Water Uses Difficult to Control," the paper being discussed by Mr. W. C. Hawley, Mr. Francis T. Kemble, Mr. James A. McMurry, Mr. Arthur A. Reimer, and Mr. Lewis P. Sawin.

(Recess till 8 o'clock P.M.)

At the evening session Dr. E. B. Rosa, chief physicist, Bureau of Standards, Department of Commerce, Washington, D. C., read a paper on Electrolysis. The discussion was participated in by Mr. Robert S. Weston, Mr. Francis T. Kemble, Mr. W. C. Lounsbury, Mr. Arthur A. Reimer, Mr. Charles W. Sherman,

Mr. W. C. Tannatt, Jr., Mr. Morris Knowles, Mr. William F. Sullivan, and Mr. J. M. Diven.

George W. Batchelder, Water Commission, Worcester, Mass., read a paper on "The Automobile as an Efficiency Agent in Water-Works Management."

A description of the new water purification plant of Miraflores, Canal Zone, submitted in print by Mr. George M. Wells, division engineer, Gatun, was read by its title.

(Adjourned to 10 A.M., Friday, September 11.)

FRIDAY, SEPTEMBER 11, 1914.

The President, in accordance with a vote of the Association at the first meeting, appointed the following committee to nominate officers for the ensuing year for the Association:

Chairman, Mr. Dexter Brackett, Boston; Mr. F. F. Forbes, Brookline; Mr. E. C. Brooks, Melrose; Mr. A. E. Martin, Springfield; Mr. F. W. Gow, Medford.

The first paper of the session was read by Mr. Frank E. Merrill, of Somerville, on "Public Watering Stations," Mr. Merrill presenting with his paper a model of the watering station being used in an attempt to prevent waste of water and curb the spread of glanders among horses. The paper was discussed by Commissioner Fred F. Walker, of the Department of Animal Industry in Massachusetts; by Dr. Francis H. Rowley, of the Massachusetts Society for the Prevention of Cruelty to Animals; and by the following members of the Association: Mr. Carleton E. Davis, Mr. Frank L. Fuller, Mr. Percy R. Sanders, Mr. William C. Lounsbury, and Mr. John H. Flynn.

Supt. D. A. Heffernan, of Milton, Mass., next read a paper on "Low Water Consumption in Milton, Mass." The paper was discussed by Mr. W. A. Hawley and Mr. J. M. Diven.

The final paper of the convention was contributed by Supt. Edward D. Eldredge, of Onset, Mass., the subject of the paper being "The Use of the Magnetic Dipping Needle in Locating Pipes and Gates." The paper was discussed by Mr. Lewis M. Bancroft, Mr. J. M. Diven, Mr. Frank L. Fuller, Mr. Herbert E. Bryant, Mr. H. T. Sparks, Mr. Charles H. Tuttle.

The chairman of the Exhibition Department at this time pre-

sented his report to the convention, and it was read by Vice-President Sullivan, as follows:

Boston, September 11, 1914.

Mr. F. A. McInnes, *President*,
New England Water Works Association,
Boston, Mass.

Dear Sir, — We herewith submit our report for the thirty-third annual convention of the New England Water Works Convention, held at the Copley-Plaza Hotel, Boston, September 9, 10, and 11, 1914.

In doing so I wish to thank Messrs. Harrison, Finneran, Brosnan, and Mulgrew, for their hearty coöperation in the work of this committee; the the Associate members, who spared no expense in providing the grand display of water-works equipment and tools; the management of the Copley-Plaza Hotel, and their assistants, for the use of their grand ball room, and willing responses to our various requirements, thus being enabled to do our share in making this the banner convention.

We wish to thank the Water Departments of the Cities of Boston, Somerville, and Holyoke for their response to the invitation we extended to the Active members to join in the exhibit, and hope that this feature will show a greater development at future meetings.

We went to a large expense in arranging the Exhibit Hall, but this has all been taken care of by the exhibitors, according to their share in the space.

I have the honor to present to you the following list of exhibitors:

A. P. Smith Manufacturing Company, The Leadite Company, Thomson Meter Company, Builders' Iron Foundry, Multiplex Manufacturing Company, H. Mueller Manufacturing Company, Joseph Dixon Crucible Company, *Engineering News*, Electro Bleaching Company, Chadwick Boston Lead Company, MacBee Cement-Lined Pipe Company, Ware Coupling and Nipple Company, The Fairbanks Company, Water Works Equipment Company, Henry R. Worthington, R. D. Wood & Co., W. R. Taylor Company, National Tube Company, S. E. T. Valve and Hydrant Company, Hays Manufacturing Company, Kennedy Valve Company, G. Frank Uhler, Neptune Meter Company, Rensselaer Valve Company, Lead-Lined Iron Pipe Company, Ludlow Valve Manufacturing Company, National Meter Company, National Water Main Cleaning Company, Pittsburg Meter Company, *Municipal Journal*, Chapman Valve Manufacturing Company, Addressograph Company, American Bitumastic Enamels Company, Ross Valve Manufacturing Company, Union Water Meter Company, *Engineering Record*, James Boyd & Bro., Inc., *Fire and Water Engineering*, Hersey Manufacturing Company, Eddy Valve Company, Standard Cast-Iron Pipe and Foundry Company, The Pitometer Company, The Westinghouse Machine Company, The Goulds Manufacturing Company, Simpson Brothers Corporation, City of Boston, City of Somerville, City of Holyoke; making a total of 45 Associates and 3 Active members.

The Exhibit Hall is still open, and we hope that those who have not already done so will spend some time with us before leaving for the afternoon excursion.

Respectfully submitted,

WM. F. WOODBURN, *Chairman.*

VICE-PRESIDENT SULLIVAN. If there is no further business, this is the close of what I believe was the best convention we have ever held, or the equal of any convention we have ever held. I trust you have all been profited by the convention and will continue enjoying the further program of the afternoon and evening. I want to call upon the President, here, to make his final bow. He pretends he hasn't done anything, but I tell you he has been working night and day on it.

THE PRESIDENT. Gentlemen, I don't see that there is anything at all for me to do, but I expressed great pleasure in calling the convention open; I don't like to express great pleasure in calling it closed, but my duty is now, I think, nothing more than to state that the convention is over. I hope you have all enjoyed yourselves and been profited.

Upon motion, the convention adjourned.

A trip to Nantasket Beach occupied the afternoon and evening.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at Copley-Plaza Hotel, Boston, Mass., September 9, 1914.

Present, President Frank A. McInnes, and members William F. Sullivan, Robert J. Thomas, Samuel E. Killam, Willard Kent, Lewis M. Bancroft, and George A. King.

The following applications were received and recommended for membership:

Members: Ernest Wadsworth, secretary Board of Water Commissioners, Duxbury, Mass.; James E. Cowper, manager Rumsey & Co., Ltd., Boston, Mass.; Horace H. Cook, assistant superintendent Kennebec Water District, Waterville, Me.; Thomas C. Sheldon, water commissioner, Fitchburg, Mass.; E. Weller Smith, superintendent water works, Glens Falls, N. Y.; L. W. F. Carstein, superintendent water company, Long Beach, N. Y.; Arthur S. Watson, superintendent water works, Oak Bluffs, Mass.; Raymond C. Allen, civil engineer, Manchester, Mass.; Charles S. Clark, treasurer Duxbury Fire and Water District, Duxbury, Mass.; Charles F. Barker, secretary Tokeneke Water Co., Rowayton, Conn.; Edward J. Tucker, in charge Mt. Hope Filtration Plant, Panama Canal, Cristobal, C. Z.; George L. Stebbins, president Seal Harbor Water Supply Co., Seal Harbor, Me.; Gordon Z. Smith, superintendent water works, Middletown, Conn.; Carleton Scott, superintendent water works, Woonsocket, R. I.; Clifton L. Rice, sanitary engineer Lowell Water Works, Lowell, Mass.; Edward G. Bradbury, engineer in charge improved water works, Akron, Ohio; W. C. Tannatt, Jr., engineer and superintendent public works, Easthampton, Mass.; John T. Carmody, water commissioner, Hartford, Conn.; Walter H. Jackson, general manager Seaconnet Park Water Co. (R. I.), Providence, R. I.; Sam C. Waldron, superintendent Watchemoket Fire District, East Providence, R. I.; Edward W. Quinn, superintendent water works, Cambridge, Mass.; John J. Corkery, superintendent water works, Norwich, Conn.; Allston F. Hart, superintendent water works, Saugus, Mass.; George H. Read, president South Egremont Water Co., South Egremont, Mass.; Walter S. Garde, president water commissioners, Hartford, Conn.; Rupert W. Wigmore, water commis-

sioner, St. John, N. B.; Eugene M. Byington, superintendent construction Boston Fire Department, Boston, Mass.; Frank J. Davis, superintendent water company, Ansonia, Conn.; William Latter, superintendent water works, Boothbay Harbor, Me.; Cornelius J. Sweeney, assistant superintendent, Stoneham, Mass.; George H. Sargent, superintendent water works, LaGrange, Ga.; Edward Drake, civil engineer, New Bedford, Mass.; J. B. Warriner, superintendent water company, Lansford, Pa.; D. H. Townley, engineer Elizabethtown Water Co., Elizabeth, N. J.; Clinton S. Howe, chairman water commissioners, West Medway, Mass.; George T. Prince, chief engineer, Metropolitan Water District of the City of Omaha, Omaha, Neb.; W. G. Aubrey, manager Spring Brook Water Co., Hudson Falls, N. Y.; W. B. R. Mason, superintendent water works, Bound Brook, N. J.; T. P. Martin, superintendent water department, West Springfield, Mass.; H. S. Clark, superintendent public works, Arlington, Mass.; George G. Anderson, consulting engineer, Denver, Colo.; Herbert E. Bryant, superintendent water works, Kingston, Mass. — 42.

Associate: Fire and Water Engineering, New York, N. Y.; Ware Coupling & Nipple Co., Ware, Mass.; *Engineering News*, New York, N. Y.; *Municipal Journal*, New York, N. Y.; MacBee Cement-Lined Pipe Co., Boston, Mass.; Columbian Iron Works, Chattanooga, Tenn.; Mutiplex Manufacturing Company, Berwick, Pa.; A. M. Byers Company, Boston, Mass.; Addressograph Company, Boston, Mass.; William P. Brew, New York, N. Y.; W. P. Taylor Company, Buffalo, N. Y.; Johnson-Washburn Co., Boston, Mass.; Epping-Carpenter Pump Co., Boston, Mass. — 13.

Thirty-two members were reinstated.

Adjourned.

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New England Water Works Association.

ORGANIZED 1882.

VOL. XXVIII. December, 1914. No. 4.

PUBLIC WATERING STATIONS.

BY FRANK E. MERRILL, WATER COMMISSIONER, SOMERVILLE, MASS.

[*Read September 11, 1914.*]

For some years past there has been in our mind a growing feeling that some better method of public horse watering than that in common use might be devised. This led last year to some experimental work along the line of individual, or pail, watering, and early this year was crystalized into definite form when an earnest appeal was received from the Department of Animal Industry of the State of Massachusetts, supported by our local board of health, for our coöperation in their effort to stamp out the rapidly spreading disease of glanders, by closing all our public horse-troughs. They requested at the same time that we furnish faucet supplies, or some like form of service, so that the horses might not suffer from lack of water.

The request fell into soil made fairly fertile by our earlier considerations of the subject, and it was but a short time before the few open public horse-troughs that we had in the city were closed— whether to remain so or not depends upon the successful operation of the individual pail system which we are now trying out.

Is the system likely to prove successful? An impartial consideration of the whole matter leads one to the conclusion that there is something to be said on both sides of the question.

I am informed by the Commissioner of the Massachusetts Department of Animal Industry and by our own board of health that the number of cases of glanders has largely decreased since open horse-troughs in our own and neighboring cities have been

closed, and it may therefore fairly be presumed that the primary object desired, the stamping out of this disease, is being assisted thereby. The proportion of this decrease in the disease rate that is solely due to the closing of the open horse-troughs may be admitted to be somewhat problematical. It would be perhaps fair to assume that some of the progress made in the reduction of the disease is attributable to a more thorough inspection and cleaning of stables and blacksmith shops, and to the difficulty of bringing horses into the state from certain directions that do not possess a clean bill of health.

The tendency of a horse to rub his nose against a watering-trough, and the possibility of a well animal becoming infected therefrom, would seem to be avoided if the structure or the conditions of its use were such as to cause the animal's head to be kept away from it.

It is probable that ninety-nine per cent. of the quantity of water flowing through the ordinary open trough serves no useful purpose, and is therefore wasted. In troughs where the flow is controlled by a ball-cock this does not, of course, apply. In the pail-watering system the waste is practically eliminated. The value of the water wasted in running troughs varies according to local conditions. In Somerville it has not been great, as the number of troughs has been small and the flow of water through them has been closely regulated. In some cities I have observed, however, that the flow is very large, — quite unnecessarily so for the object to be attained, — and the money value of the water thus wasted must reach quite a large figure.

In expression of gallons per capita the waste of water from the open troughs in Somerville would undoubtedly be but a small fraction of one, probably less than one quarter and possibly as low as one tenth. In terms of dollars and cents, a reduction of one gallon per capita daily in our water consumption means a saving in our metropolitan water assessment of $1 250 for the year, and the cost to our city on the above basis for water thus wasted would be, therefore, less than $300 per year. Not a large sum, to be sure, yet one to be saved if what it represents is of no real benefit. From observations of the flow of water through troughs in some cities it would seem as though the waste, figured

on the same basis, must reach into thousands instead of hundreds of dollars.

The large size of the common open trough restricts its installation in congested districts to comparatively few localities, such as public squares, wide streets, or similar open spaces. This tends to keep the number of horse-watering opportunities comparatively small. Some method of watering that is inexpensive in its construction, occupies but little room, and that can be installed in a city sidewalk at frequent intervals, would seem, therefore, to possess distinct advantages.

While the application of faucets to fire hydrants for such purpose is a simple and easy way of furnishing individual supplies in a sufficient frequency, I do not feel that this use of the fire service of a city is to be commended, especially if the hydrants are not equipped with outlet valves, and should regard this method as a temporary expedient only.

I suppose that no watering device is so pleasing to the lazy driver as the common open trough, where he can sit at leisure enjoying his pipe while his tired and perhaps overheated horse drinks from the flowing bowl to his heart's content and quite possibly to his stomach's detriment.

There is a probability that the danger of overwatering horses on hot days, causing colic and indigestion, is largely averted by the pail system, and possibly as much distress is saved the animals in this way as is caused by the failure of drivers to offer them water when it is needed.

This laxity on the part of some drivers to water their horses on account of the extra effort involved on their part is advanced as an argument against the adoption of the pail system, but it would seem that the city or town had done its part when it willingly furnished an abundance of water for the animals without cost, and it should not be expected that in addition it should furnish means whereby a lazy teamster may do his duty without any exertion on his own part.

But observation shows that the watering stations in Somerville are largely patronized and are appreciated by teamsters, and we may hope that the number of drivers who will not exert themselves sufficiently to attend to the needs of the animals in their charge

at these convenient stations is very small, and that the class will soon become obsolete as the new habit is acquired.

The new public watering stations in Somerville are an experiment, and the object of this paper is to bring them before you as a suggestion of what may be done along this line rather than to lay any particular claim to their efficiency as a new departure.

The keynote of the Somerville watering-station construction is "simplicity." This device may be described as being in its essential parts a piece of 12-in. cast-iron pipe set in the ground with its bell-end upwards, the face of the bell being 29 in. above the sidewalk grade and the other end being a sufficient distance below the surface to obtain stability. An ordinary service pipe from the street main makes into a 2-in. riser which comes up through the center of the standard and is held in position by a cast-iron strainer resting in the bell of the large pipe. This riser is capped with a side-outlet cross standing 12 in. above the top of the bell end of the pipe, which forms a convenient ledge upon which to rest a pail while filling. Into one of the outlets of the cross is inserted a $\frac{3}{4}$-in. self-closing hose bibb, so that a hose line may be attached if needed for any purpose; into two other outlets are inserted self-closing plain bibbs, and into the outlet facing the sidewalk is fitted a bubbler controlled by a self-closing cock. In this condensed space there are found, therefore, opportunities at once for three teamsters to draw water and for another one to obtain a refreshing draft for himself.

Attached to the side of the 12-in. standard near the sidewalk grade is a bowl for dogs, which is kept supplied with fresh water by the drip of the bubbler overhead, the water being caught in a tunnel set underneath the strainer and conveyed through a small pipe into the dog bowl.

The waste from the faucets and dog bowl is discharged into the interior of the 12-in. standard, which has a cement bottom, and an opening allows the water to escape into a drain pipe leading to the sewer, or if preferred into the gutter.

On the side of the 12-in. standard under the bubbler is fastened a step at a convenient height for children to reach the water from that fixture.

All the materials used in the construction of this watering sta-

PLATE III.
N. E. W. W. ASSOCIATION,
VOL. XXVIII.
MERRILL ON
WATERING STATIONS.

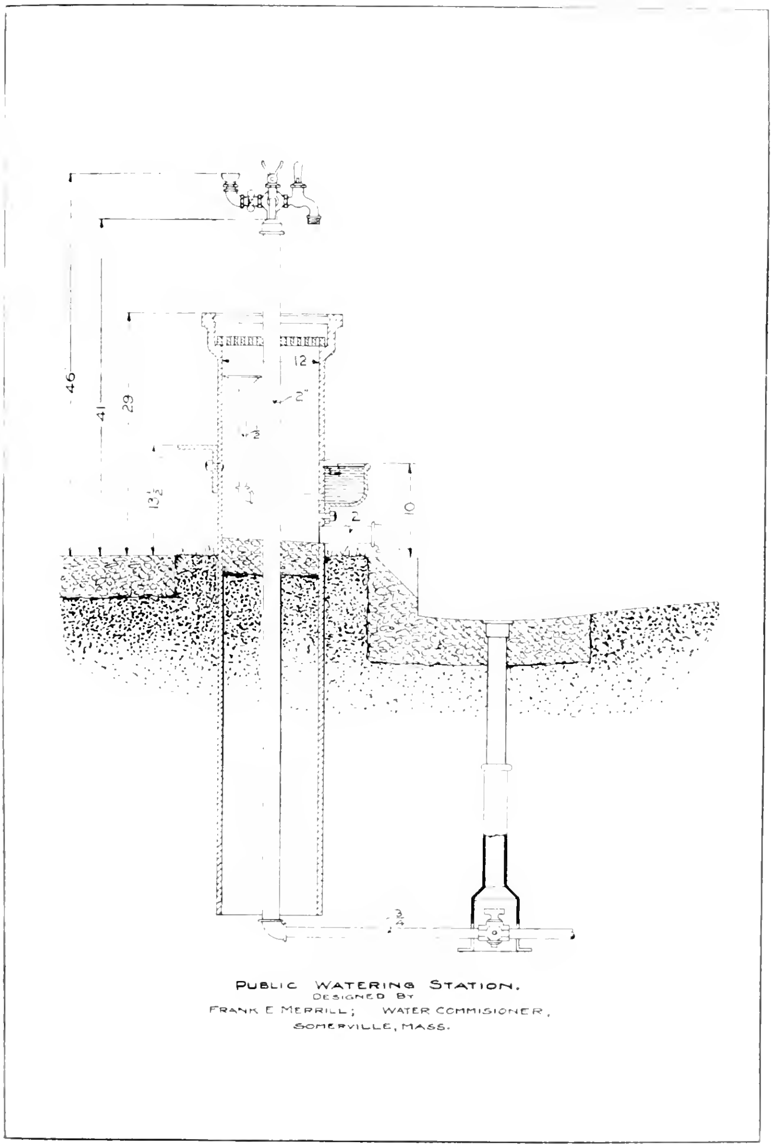
46
41
29
12
2"
$1\frac{1}{2}$
$13\frac{1}{2}$
10
2
$\frac{3}{4}$
PUBLIC WATERING STATION.
DESIGNED BY
FRANK E MERRILL; WATER COMMISIONER,
SOMERVILLE, MASS.

FIG. 1.

tion are — with the exception of the castings for the strainer, dog bowl, and step — such as are found in every water-works shop or supply house. The cost of the outfit made up in your own shop and ready to set in position will be found to be about twenty dollars, and if you add as much more for the cost of installing it, with supply and drainage connections, you will have a pretty complete watering combination at a very moderate outlay of money.

I feel that I can speak with some degree of assurance as to the simplicity and low cost of this form of watering station. Its efficiency as a horse-watering proposition is perhaps yet to be fully demonstrated in my own experience.

DISCUSSION.

MR. FRED F. WALKER.* *Mr. President and Gentlemen,* — I am grateful for this opportunity to express in a public way my appreciation of the hearty coöperation that has been invariably extended to me by the officials who have charge of the water systems that supply the citizens of the Commonwealth.

The state department I have the honor to represent is charged by statute law with the control of contagious diseases among animals. One of the most serious diseases we have to contend with is that of glanders. This deadly malady had prior to 1913 assumed, especially in Boston, alarming proportions. Early in that year the Department of Animal Industry undertook the arduous task of bringing the epizoötic under control. Various remedial measures were inaugurated with but indifferent success. In spite of all our efforts the disease remained a serious menace. Glanders was being communicated and was spreading in the face of sanitary preventive treatment. The truth of the matter is that we were not getting at the source of the trouble, and finally I petitioned the Public Works Department of Boston for relief from that device, most uniformly dreaded as a spreader of glanders by those who are in a position to know, the public drinking-fountain for horses. I was referred by the public works commissioner to the superintendent of the water department, by whom I was

* Commissioner of Animal Industry, Massachusetts.

extended every courtesy, and together we evolved a plan by which the danger of spreading the disease should by minimized, and at the same time the comfort of the animal assured.

The plan was the simple one of closing the flowing drinking-fountain, and installing an auxiliary tap so that drivers, by the use of their own pails, might supply water to the horses in their charge while on the streets. This regulation finds its counterpart in the antiseptic cups required in railroad trains, in the "bubbler fountains" now so generally in use in school rooms and in the streets, and in the order dispensing with the open faucet in public places. It is but another proof, and a practical one, of the old-time saying, "An ounce of prevention is worth a pound of cure." Not only are we aiding in checking the spread of this disease by closing the fountains, but we are also doing the horse another favor and, incidentally, his owner, for in place of the horse when heated drinking too much, by the use of the pail he is kept from extreme indulgence and thus avoids the danger of digestive troubles so generally prevalent during the heated term.

The coöperation and courtesy shown by the water officials of Boston have been duplicated by similar officials in most of the cities and towns in Greater Boston, until practically everywhere within the metropolitan district this preventive measure is in force and operative, with satisfactory results as you shall see a little later. This is no fad of mine. In this work for man and beast — for glanders may be communicated to the human as well as the animal — the personal equation is absent. We are working to advance the health standard, and we know no better way than to use every known means of prevention.

But nothing is done in connection with this work I can assure you, until it has been carefully considered by expert authorities. The decision to close the public drinking-fountains or open troughs was the logical conviction born of the department's experience which was supported and approved by the most eminent authorities in veterinary science in the United States.

During all the time the flowing fountains have been closed, I have not received a single protest from a horse-owner. On the contrary, I have had the most flattering endorsement of my policy from the largest and most representive team-owning firms in

Boston, as well as a letter of commendation from the largest organized body of horse owners in the state, and hundreds of approving messages from men owning only a few horses but equally interested in the health of their animals.

And while on this point let me name a few of my many advisers, — men who are of national if not world-wide reputation on this subject. I am permitted to include in my advisory staff Prof. Theobald Smith, professor of comparative pathology, Harvard University Medical School; Prof. V. A. Moore, director of New York State Veterinary College at Cornell University, Ithaca, N. Y.; Dr. A. D. Melvin, chief of the United States Bureau of Animal Industry, Washington, D. C.; Dr. C. J. Marshall, state veterinarian, Live Stock Sanitary Board of Pennsylvania; Dr. J. G. Wills, chief veterinarian, State of New York Department of Agriculture.

The plan has not been in vogue very long, but I am sure you will agree with me that the results are most encouraging. The flowing fountains in Boston were closed November 1, 1913. From December 1, 1912, to September 1, 1913, there were 401 cases of glanders in the city of Boston; the horses were either killed or died. From December 1, 1913, a month after the order went into effect, until September 1, 1914, only 262 cases were of record, a decrease of 139 cases. If we had simply prevented an increase of the cases reported in 1912, we should have been justified in feeling that we had put an effective check upon the disease, but when we were able to reduce the cases in nine months almost 35 per cent., we naturally are confirmed in our estimate of the effectiveness of the step.

In closing I wish to say that any and all of you, who can spare the time, will be welcomed at the department headquarters in the State House. I shall be happy to place before you the records of the office in relation to glanders control, and to show you the originals of the letters I have received favoring the individual drinking pail for horses in infected areas.

The President. I think I can safely assure Mr. Walker that water-works people as a whole are willing to help him in this great work of disease prevention in no matter what line. They have taken up the matter of water sanitation, and they are willing, I

believe, to take up the matter of sanitation from outside sources other than water itself. This device of Mr. Merrill's shows the interest that water-works people take in those things when asked to coöperate with those that want to stimulate that kind of work.

DR. FRANCIS H. ROWLEY.* As Mr. Walker said, the point where his department of the state came into contact with your own is where the horse is the interested subject. Now, that is just where our point of contact also is made with your organization. However mistaken I may be in the attitude I take, you surely will not accuse me of not being intensely interested in the horse. I am not a veterinarian. I have owned horses, from one to three driving horses, all my life. I have studied them, their anatomy, the inside of them and the outside of them, and have had the personal care of them for years at a time. I have always been observant of horses. So when Mr. Walker came to me last autumn and said, "We are thinking of closing the watering troughs in the city of Boston, for the prevention of the spread of glanders; we would like to know how the Massachusetts Society for the Prevention of Cruelty to Animals feels about it," — well, inasmuch as I had done all that was in my power to do to have this matter of the control of glanders put by the state into Mr. Walker's department, and inasmuch as I was very anxious to have glanders reduced, stamped out, if possible, I said, "Well, as a temporary expedient I have no objections, — the Society will have no objections, — though I thoroughly believe that what we call the sanitary fountain as a source of spreading glanders is so trifling as hardly to be worth consideration." I am led to believe, from all I can learn, that it is the purpose of the department to make this a permanent thing, and, so far as they can, never again to have open watering-troughs in the city of Boston.

Now, I am just as much opposed to the dirty open watering-trough as anybody can be. The city of Boston used to keep two men traveling constantly about the city cleaning out its open watering-troughs, and we were not in the condition of those people in New York City, who complained that the fountains they wanted closed were fountains in front of saloons that spittoons were washed

* President of the Massachusetts Society for the Prevention of Cruelty to Animals.

in in the morning and that children took their baths in, and that dogs and cats were bathed in, because our fountains were kept in a very decently clean condition. The thing that I do believe in is a watering-trough that furnishes horses at every opportunity that they can obtain it good, clean, flowing water, thoroughly believing that water in that condition becomes so trifling a source for the spread of glanders as to be hardly worth consideration. I do realize that the matter of cost — probably more and more as time goes on — will have to be considered by you gentlemen and by our cities. It is very much more economical, I am sure, to water horses by a device of the sort now in use than by the open, flowing bowl. The difficulty is that the average driver will not take the trouble to get off from his seat and take his pail and water his horse. I have taken pains to sit in a place where I could observe fountains in the city of Boston, or the places where these things have been established, and I have not only seen drivers come up and damn the city and everybody else because the fountain was closed, but I have seen them borrow the pails of their fellow-drivers and water their own horses with them, and in some cases — not a few — I have seen them come up, find that there was no water, and though there was a sign there that water could be obtained here at a faucet, drive on their way and let their horses go thirsty.

As to the matter that was spoken of here, the open fountain giving too much water. Now, I think all men who know anything about a horse know that the thing a horse wants is water often; then he never drinks in a large quantity if he is watered frequently. A veterinarian said in my office that a fellow veterinarian said to him, " You are not going to oppose the closing of the fountains, are you? Since the fountains were closed in Boston, I have had more business than in my whole life, because these horses, so many of them going without water through the day, come in at night and drink a barrel full, and about twelve o'clock I am called."

As I said to you, my opinion in this matter isn't that of a veterinarian, but I wrote a letter to every veterinarian in the state of Massachusetts, about three months ago, and I told each of them that our fountains were closed and asked if he would tell

me what his judgment was as a result of his knowledge and his experience as to the wisdom of it, and whether in his judgment more suffering came to the animals from going without water, as they might be deprived of it, or whether more suffering came from having them open and taking the chances of contagion from glanders. Well, I was surprised that, out of 426 letters sent to 426 veterinarians — the list given me by the registry of veterinarians of Massachusetts — every letter enclosing a stamped envelope for reply, only 143 replied. Of these 143 veterinarians of all sorts, — good, bad, and indifferent, — almost 60 per cent. replied that according to their judgment and experience it was a very foolish thing and hard upon the horses to have the fountains closed. So this is not absolutely a matter upon which I am speaking, though a layman, without authority.

I want also to bring you a few other facts concerning our own city. In the first six months of 1909 there were 116 cases of glanders. In the first six months of 1910 there were 157 cases of glanders. In the first six months of 1911, there were 181 cases of glanders. In the first six months of 1912, with the fountains all open and nothing being done in an excessive degree to prevent the spread of the contagion, it dropped to 155. In 1913, the first six months, it rose again to 199, and during the first six months of 1914, — that is, this year, — it has dropped to 166. Now, between 1911 and 1912, taking the first six months of the year, with all our fountains open and no quarantine from outside of Massachusetts against horses coming in here with glanders, and not a great deal being done toward the disinfecting of blacksmiths' shops, we had a fall in those first six months of 26. Now, with the quarantine against New York and Connecticut and Rhode Island, and with orders issued to blacksmiths' shops and others to disinfect their stables, and with all the fountains closed, they only gain 33 cases. So it would not seem, from the statistics, that all the gain had come from the closing of the fountains. I am certainly willing to admit that the average dirty trough, and even the average clean trough, is a possible source of contagion, but that it is the chief source is, I believe, an absurd statement.

Let me quote you from experience abroad. The London Watering Trough Association has been engaged for many years

in watering horses. It waters in the city of London over half a million horses a day. In 1903 they had — I will give round numbers — 2 500 cases of glanders. In 1904 they had 2 600 cases of glanders. In 1905 they had 2 000 cases of glanders. In 1906 they had 2 000. In 1908, 2 400. In 1909, 1 700. In 1910, 1 004. Then in 1911, 502. In 1912, 316. What happened between 1908, when they had 2 400 cases, and 1912, when they were down to 316 cases, the last quarter of that year having in the whole city of London only 24 cases of glanders? Why, the government of Great Britain had introduced the Glanders Act, which recompensed every man in Great Britain who had a glandered horse for his horse when the horse was destroyed. That made it a very much easier thing for the man whose horse had glanders to report his horse and have it destroyed, and it took out of the community a constant source of the spread of the contagion. Of course, the situation is different, very much different here; because we have no national law here, as they have abroad. This is what happens in Massachusetts in I don't know how many cases, — I know personally of some: A veterinarian goes through a man's stable, containing 25 or 30 horses, more or less, and he subjects them to the Maline test, and perhaps, as I know happened in one case, of about 40 horses, nearly half reacted. It was a hard thing to say to that man, "Your horses have got to be destroyed," — eighteen or twenty of these good-looking, fat, sleek, comfortable horses which had reacted to the test. It was not done. Those horses, some of them, are working to-day in the city of Boston, and the authorities know, and a number of us know, that they are horses that have reacted to the Maline test. What are we going to do? Does a veterinarian want to go into your stable, if you have 100 horses and 25 of them reacted, and kill them? Not till the state is willing to pay the man that owns the horse a sufficient recompense so that he will not be tempted to keep his horse or sell it to somebody else. Another thing that happens in the state of Massachusetts is that a man who has a large number of horses, more or less, brings them to the veterinary and has them subjected to the test, — not done under the Bureau of Animal Industry but as a private matter, — and this veterinarian says to his client, "You have six or

eight horses here that react," or a dozen or twenty. What does he do? He proceeds quietly to work them off into the community through sales stables and in other ways. That is a thing that is going on. And up till we had our quarantine we had horses that could be brought in here from many states without any bill of health. And I believe it is possible for them to come in from the West without any bill of health; and, so far as I know, if a man wanted to go into Chicago and buy a carload of horses that in a private stable had reacted and given evidence of being glandered horses, and ship them into Boston, there is nobody to head them off and say, "Where is your bill of health certifying that these horses are in perfectly sound condition?"

Here is the opinion of Professor Hunting, Fellow of the Royal College of Veterinary Surgeons, and inspector of the London County Council. This gentleman says:

"One more method of spread [of glanders] I must refer to — the public water trough. It is rather curious that some men have picked out this most useful institution for special attack. It is quite possible that some cases of glanders have arisen as the direct effect of drinking at a public trough, but they are very few and far between. I have an intimate knowledge of the stables of three contractors who have had during the last twenty years four outbreaks of glanders in their studs. Each outbreak was clearly and directly traceable to the purchase of a horse from an infected stud, and was stamped out at once without spreading. *Save these outbreaks, no glanders has troubled them, and yet their horses travel all over London and drink at any water trough they can reach.* I feel convinced that infection from water troughs is very rare, because in 90 per cent. of all outbreaks which I have personally investigated, other methods of infection are traceable. Even if 5 per cent. of all outbreaks in London were traceable to the water troughs, the gravity of the harm would be no argument in favor of closing the troughs, especially in summer. *The harm resulting to horses from being denied water all day would cause a mortality greater than is caused by all the glanders in the metropolis.* The fact that an occasional case of glanders may be due to public water troughs is an argument for the extermination of the disease, but not for closing the troughs. . . .

"Nothing leads to fatal abdominal diseases in horses more certainly than an irregular and insufficient supply of water.

"Even if it could be shown — *which it cannot* — that the water troughs infect horses with contagious diseases occasionally, the

advantages to hundreds and thousands of horses whose thirst is quenched, and colic prevented, would be an argument for the existence of the troughs."

Watering half a million horses a day in the city of London, as they have been watering now for over twelve years, if the fountain was a great source of spreading this disease you would think that nearly every horse in London ought to have the glanders. Instead of that there has been with this Act such a marked diminution that it looks as though in a few years they would not have a solitary case. When the head of the Animal Department of Canada lectured last winter here at the Harvard Medical School on this question, I spoke with him at the close of the lecture, and he said that they had practically stamped out glanders in Canada. I asked, " In stamping this out of the Provinces, did you close any fountains? " He said, " We never thought it wise or necessary to close a single fountain." But there again you have the same condition, a national law by which compensation so abundant is given to every owner of a glandered horse that he does not try to conceal it or work it off among his fellows.

What I want to see is the most abundant supply of water furnished the horses of our cities and towns of Massachusetts that it is possible to furnish them under the most sanitary conditions. If it ever can be demonstrated that by the closing of every fountain you can wipe out glanders, I am willing to accept the statement, of course, but until many other things are done it seems to me to call fountain, which is the least of all the causes of the spread of glanders, the greatest, is to begin absolutely at the wrong end, or to spare at the spigot and to waste at the bung-hole.

VICE-PRESIDENT SULLIVAN. This is of much interest and importance to water-works people, particularly at this stage when we are talking so much about conservation. This type of watering station here is coming in to help us to save Massachusetts water. The old-fashioned watering trough on measurements taken could use from fifty to a thousand dollars' worth of water a year. It may be a small item in some places, but in places where they have to conserve the water it is of much importance.

MR. CARLETON E. DAVIS. *Mr. President,* — Philadelphia has between five hundred and six hundred public horse-watering-

troughs. Last May Dr. Marshall, state veterinarian, ordered them closed on account of the prevalence of glanders in the city. Up to May, about fifty cases of glanders had been reported.

A large number of the horse watering-troughs were closed without trouble. Some, however, remained open owing to complications arising from the fact that prepayment had been made on these fixtures.

Since the troughs have been closed, I am informed that the number of cases of glanders has decreased, though I cannot give actual figures.

A number of large team-owners have coöperated heartily in the effort to use individual pails as a substitute for the troughs. Other horse owners did not apparently coöperate heartily, and certain of the societies for the prevention of cruelty to animals were likewise antagonistic to the closing. For instance, one of the officers of one of the women's societies placed a spigot on the curb in front of her house and then put up a sign: "A pail for watering horses will be found in the bushes inside the yard." Of course she sympathized with the horses, but that common pail meant a condition practically identical with the public trough.

No effort has yet been made to control the common watering-trough in stables.

I am interested in noting the attachment for dogs in the sample watering-trough exhibited here to-day. In Philadelphia a great deal of sympathy has been expressed for the birds and dogs.

It seems probable from the sentiment which has been expressed here to-day, and the sentiment which has developed in Pennsylvania, that the common watering-trough is on the road to be permanently abolished.

Mr. Geo. F. Stebbins.* This is a subject in which I have been much interested for several years past, particularly as to what extent the watering of horses in this manner contributed to the transmission of the very contagious and always fatal disease known as glanders.

I am well aware of the differences of opinion on this subject by experts and the public expressions, *pro* and *con*, in connection with the closing of these troughs by the Commissioner of Animal

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* Secretary Team Owners' Association, Boston.

Industry, and would present to you my reasons for being heartily in accord with this act.

For four years I have had 1 000 horses, belonging to members of this Association, under close inspection for glanders, every case being reported to me, and in this way have been able to collect some statistics that may be of interest. For the first three of the above years the average loss by glanders amongst these animals was between four and five per cent. of the total number per annum. Since the closing of the troughs, the loss by this disease figures less than one third of one per cent.

While there are many ways by which this disease may be communicated, my observations lead me to believe that the public watering-troughs have been the most fruitful, and the closing of them thoroughly warranted, as it entails no deprivation or hardship for man or beast.

Mr. Frank L. Fuller. I would like to ask about the individual bowls in horse-watering troughs, where I think each one is supplied by a separate supply and is running over constantly. Are they largely used?

Dr. Rowley. I think the reference is to what is known as the Jenks fountain, which provides what is practically a bubbler fountain for the horse. The criticism upon that is that in cities and towns where you have a limited supply of water it is expensive. Here in Boston, where I imagine we have an abundant supply, — at least, the city has never objected to furnishing all the water we wanted for the fountains, — I think it would not cut very much figure. There is, however, invented by a gentleman in the South, and working at Tampa, Fla., a fountain on the same principle, a bubbler fountain, but the horse must step on the little iron platform as he comes up to this bowl to drink, when immediately the water gushes in and overflows the bowl, and as soon as he backs off the cock is closed and the flowing stops. That is working, and working very successfully. Then there is practically no waste of the water because the bowl gets a flush at the last minute before it is finally turned off and waits for the next horse.

Mr. Walker. Further answering the gentleman's question from the standpoint of the objection, the individual drinking cup as installed in some of the stations in Boston, as they were operated

prior to the time they were closed, did not eliminate the great danger that we appreciated in these public stations, namely, the shelf on which the horses diseased with glanders may deposit the germs, which in turn would be acquired by the horse that follows and rubs his nose, not on the water, but on the shelf that surrounds the water.

Dr. Rowley. If I might say one word more: Mr. Walker is scientifically, theoretically right, — that is all. But you probably cannot get into a street car that does not harbor a lot of germs of various diseases, — tuberculosis, pneumonia, typhoid fever, etc. You can't live in this world without breathing in bugs and germs constantly, and if you were in a particularly susceptible condition to-day and the germs get in their work, you are a goner. The other bugs inside of you may not be sufficient, in their state of health, to knock them out. In the same way, if a horse is in the condition to get glanders and gets his nose just where another horse blew his, not having a handkerchief, he probably will get into trouble. But you can go into a theater where there are any amount of germs, or nurse patients with various diseases, and yet not suffer harm if in good health.

Mr. Walker. I have no disposition, any more than Mr. Rowley, to monopolize all your time. He has said that I was theoretically right, and I appreciate the compliment. What we contend more forcibly than that we are theoretically right is that we are practically right, because we are getting results. We have the results in the nine months in Boston. We have the further evidence that we are practically right by the absence of an objection, as I have said before, by one team owner of importance. And we have not had an objection and I believe that that is evidence that we are practically right, because these same team owners are studying this situation. They have taken advice from veterinarians in whom they have confidence, and they have concluded, as a result of their interviews with their own veterinarians, as a result of their observation of their own horses, that we are practically right. Therefore, instead of condemning this move, they are commending it.

Mr. Percy R. Sanders. May I ask Mr. Merrill how he expects to take care of these fountains in the winter.

Mr. Merrill. So far, we think that we shall either close them in the winter or, if we can have authority from Mr. McInnes to install some of the very clever devices which he has arranged for his own use, we can allow them to remain running all winter without any danger of freezing. I am very glad you spoke of that, because I want to call your special attention to the fountains which the Boston water department has on exhibition here, and particularly to that clever arrangement of taking care of the flow of water through a small connection underneath this self-closing cock, which allows a small stream of water continually to run through the pipe, and prevents its freezing, and yet is not large enough to cause any great waste. I hope before you leave you will all take a look at that arrangement.

Mr. William C. Lounsbury. Mr. President, as I understand Mr. Walker, what he said applied wholly to glanders. I would like to ask him if there are other horse diseases that appear to be spread from the public watering-trough fountains.

Mr. Walker. I can answer that question purely on advice given me by those who in my opinion are the best authorities on such subjects in this and other states. They have invariably advised me that, so far as the spread of any disease was concerned other than glanders, the watering-trough was not the material cause, if of any importance, outside of its influence on horses relative to their digestive troubles. Dr. Gill, of New York, who is recognized as the leading veterinarian of that city, told me that there was a general protest in New York at the time the troughs were temporarily closed there, on the part of veterinarians, because of the marked diminution of colic cases. While I am making no particular claim in reference to such diminution, the advice I have received on the subject all tends to indicate that the absence of opportunity for horses that are heavily loaded and have been perhaps without water half a day to be driven to a trough where the water is running practically ice-cold and where they are allowed to stand and take into their systems much more than they should, or would if the driver realized how much it was until after he noticed the horse's bulging sides, — the elimination of such opportunities has materially decreased the cases of colic. But referring to other cases than glanders, I think it has not any importance.

Mr. Lounsbury. I just wish to make this observation: We have at Superior a city veterinarian connected with the Health Department. The 1st of August the local water company was notified by the Health Department, on order from the city veterinarian, that the city watering-troughs should be closed. It seems in this case there was an epidemic of dysentery.

I think it might be of some interest to note that we have a new type of fountain in which there is a combination bubbling fountain for people which is continuously flowing, and an overflow from that which goes directly down into the horse trough; thus there is a continuous flow of water out from the trough.

Mr. John H. Flynn. Mr. President, I would like to ask Dr. Rowley if there has not been an epidemic before this last one. Also if he has in mind that in the epizoötic of 1872 they did not shut the water off from the horse troughs.

Dr. Rowley. I haven't the records back of 1909. There was a report circulated within this year that there had been a recent outbreak of glanders in London. I wrote at once to the secretary of the Association, and have his letter in my possession, to the effect that there had been no outbreak of glanders any more than the usual number of cases during a number of years. I think it is perfectly true that there are outbreaks of glanders, as of other diseases.

Mr. Walker. I feel that we could hardly say that there had been an epizoötic of glanders in Boston at any particular time because of the fact of record that for the ten years prior to the present year there had been a steady and rather more than gradual increase in the cases of glanders annually in that territory. In other words, it was growing on the authorities continually, — with some variations, to be sure, as Dr. Rowley has alluded to. At times there would be slight fluctuations in favor of the contention that might be made that the matter of the subject was under control.

Now, this matter is not settled, gentlemen. We are not here to say that we have the problem all solved, because it may be possible for any one who is inclined to doubt the efficiency and the advisability of adopting this measure of prevention to say next year that we have failed. But, so far, everything seems to

indicate that we are on the right track, and so long as we are I believe that you men are practical enough to say, with the team-owners and with the Department of Animal Industry, — let us stick to a policy that seems to be so far so creditable. As to the effect of the epizoötic that was so prevalent at the time of the Boston fire, I am of the opinion that that was in the nature of paralysis, — where the horses were attacked by some sort of paralysis. I don't know just what the character of the disease was, but I do not think it was in every sense a glanderous outbreak. I understand it was contagious. Naturally we would assume that the troughs, or any place where contagion should have been spread, should have been closed, but possibly the authorities were not as wise in their day and generation as those of to-day take credit for being.

WATER USES DIFFICULT TO CONTROL.

BY WILLIAM F. SULLIVAN, SUPERINTENDENT OF WATER WORKS, NASHUA, N. H.

[*Read September 10, 1914.*]

Wherever water is sold on the basis of flat rates or special rates, or where privileges are granted to some and not to others, even when it is not feasible that all could avail themselves of the priviledge, it is difficult to closely control the use of water.

When it is incumbent upon water-works officials to control the use of unmetered water, it often appears that they require the assent of the governed. Municipal and town works are in much better position to govern water uses than are private companies. Municipalities and towns may make rules, regulations, and ordinances with almost the power of a statute, with authority to enforce the ordinance and penalize those who break or abuse the regulation.

If municipal water departments work in harmony with the other city departments, the governing and controlling of visible wastes and leaks are made less difficult. Particularly is this true when police departments report infraction of the rules.

The authority of private companies to enforce their rules is more limited than that of cities or towns. It is much simpler to govern when you are assisted by established laws, especially when they have been reasonably enforced from the beginning or for a long period. It is a well-known fact that most water works have at some time or other been lax in regulating certain uses of water. This often happens for economic reasons. Sometimes it pays not to enforce the rules. When the practice has been not to rigidly enforce the rules against what might be termed small or everyday wastes, and this laxity has made water takers careless and they have acquired the habit of using water uncontrolled or unregulated, it is no slight task to gain control.

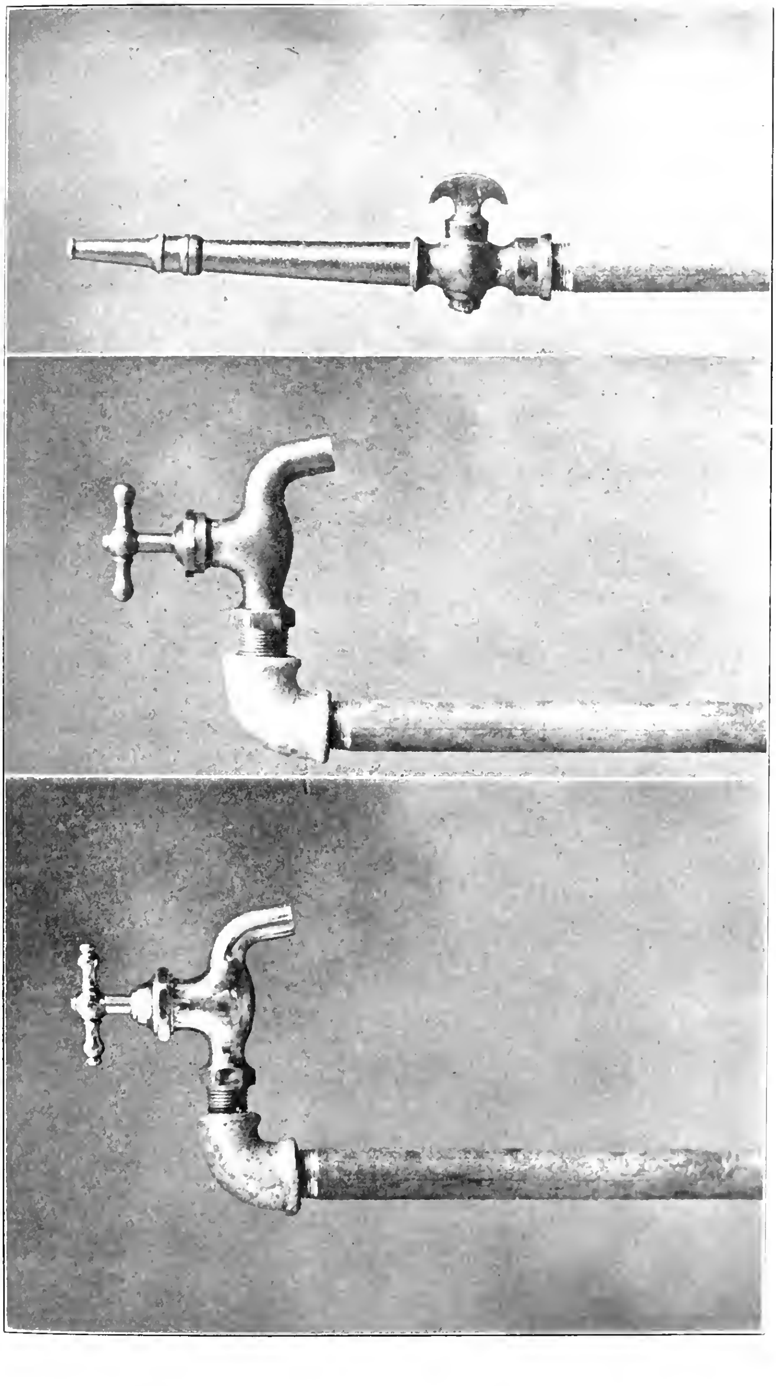
Suddenly, for any of a number of reasons, it becomes necessary to restrict the uses of water in conformance to rules, and people who ordinarily have respect for law and constituted authority take the attitude that the water works is arbitrarily taking something from them, which they have always had, if not by law, then by custom.

The task, then, is to convince these people that a water works, like any other business, to be successful must be managed; that one of the cardinal rules of business is to use all alike; and that all customers should pay in proportion to what they use or get.

Former methods in the management of water works, still practiced in some places, have misled water takers to believe that because of former customers and because they have been paying a flat rate ungoverned, they are still entitled to use or waste water for any purpose they wish, even for power. These people will sometimes advance the hackneyed argument that "water is free, or ought to be free." They dismiss from their minds the value of water or service, and oftentimes exclaim: "The water is on a hill and only has to run down." Such statements as these are made regardless of whether the supply is on a hill or at sea level, or whether it is a conserved and protected supply or a filtered water. Some who give little thought to where the water comes from, or why it is ever ready at the faucets, give less thought to the fact that it costs money to produce good water.

In controlling the wasteful and profitless use of water, some water takers would lead you to believe that they do not want to pay their proportionate share, and frequently fall back upon the stock argument of rates, belittling their own supply and comparing the rates of their community with another with which they are familiar or have heard about, regardless of the facts, size, source, kind, or service of the works used in comparison. They usually neglect the elements of money invested in the plant or the cost of production. Usually the illustration is some municipal plant where rates are regulated by municipal authority and not by those who manage the works.

Municipal governments are short lived. While in control of affairs they seek the approval at times of citizens who do not give attention or study to municipal finances. Seldom do they con-



TYPES OF SINK FAUCETS AND NOZZLE TESTED.

sider in figuring costs of production all the elements chargeable to cost. The water works which does not figure its true cost of production usually has a misleading rate. The revenues of an established water works should cover operation and maintenance, the interest on the investment, depreciation, taxes, and in some cases a sum for a sinking fund to pay off bonded indebtedness. Quite often cities determining upon rates consider only the items of operation and maintenance. The tax levy or loans supply the deficit and money to pay for new construction, and sometimes even for renewals.

In order to meet all the elements of cost, it oftentimes becomes necessary to control and regulate the use of water. It is not to be supposed it was ever intended that these special uses or privileges should be allowed, and there is a growing understanding of what is legitimate use of water and what a reasonable and true rate should be.

It is not the scope of this paper to deal with major uses of water, such as fire services, etc., as this use at the present time is becoming well controlled, and there is a better understanding among water-works managers, underwriters, and the assured. Rather is it intended to treat of so-called minor uses difficult to control.

When the water rate for building purposes is a flat one, usually nominal, based on the size or kind of building, there is a waste due to the carelessness, sometimes willful, of the workmen. Much water for drinking purposes is allowed to run to waste. The workmen take a drink from the butt end of a hose or faucet, usually about a pint, the end of the hose is then dropped to the ground and left running. The discharge from the butt end of a hose with sillcock open one half is 9 gal. per minute. The water may be allowed to run to cool before taking a drink, and thus from 7 to 16 gal. per minute is wasted. Observations show that from 10 to 4 000 times as much water is wasted as drunk during the summer months on building construction.

For slaking lime and the tempering of mortar, the mixing of cement and concrete, on small jobs, the mason's helper or attendant, as a rule, does not shut off the water when he has enough for the needs at hand, but drops the butt end of the hose on the ground or sticks it into a cask already full of water, and the overflow runs

over the edge in a miniature waterfall. Quite often at quitting time the attendant goes home neglecting to shut off the water for the night.

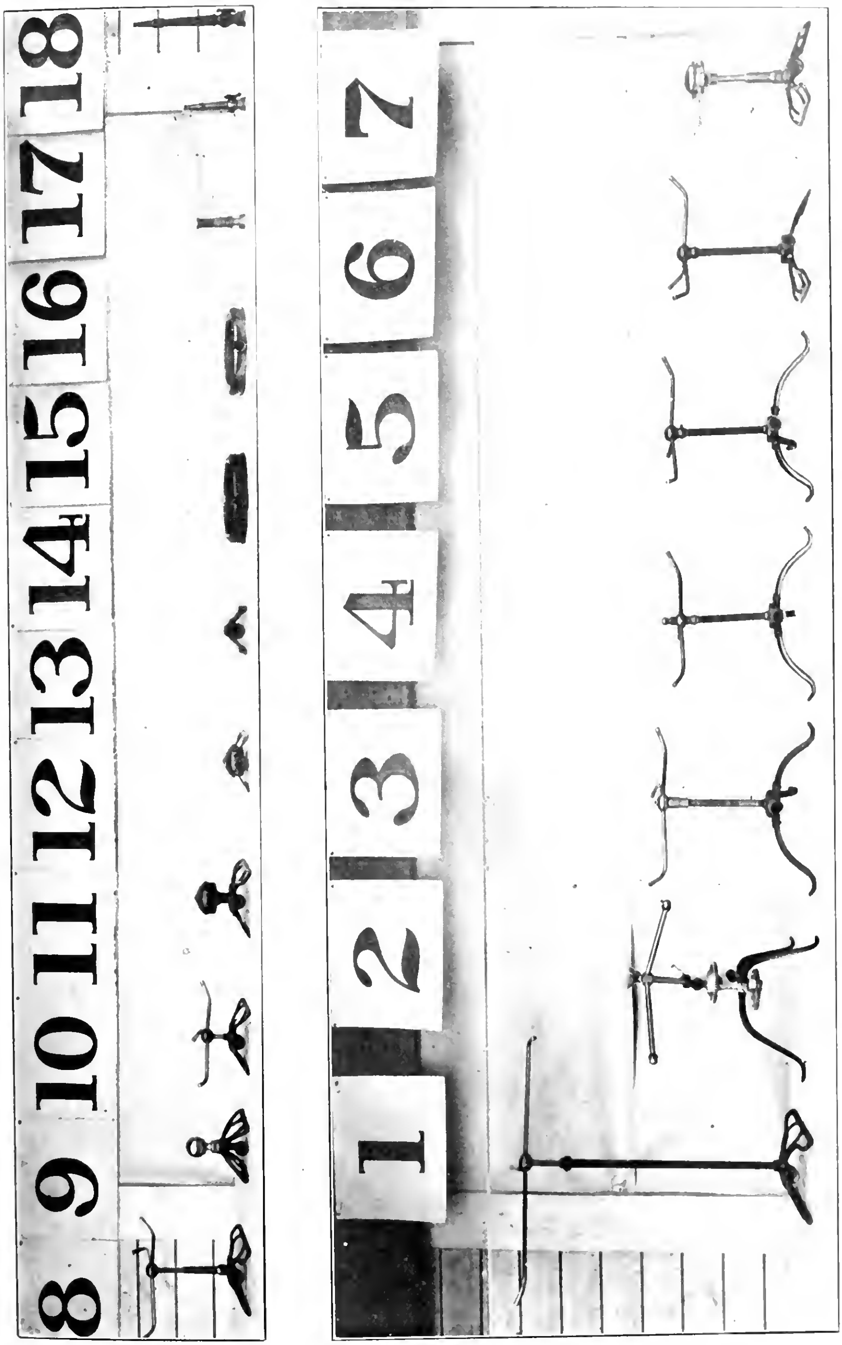
If the rate is a fixed sum per cask for lime or cement, averaging about 6 cents, the above-mentioned wastes are as frequent. Those who pay 6 cents per cask realize that the rate is excessive. Those who do the work know that it takes about 50 pails full, or 125 gal. per barrel of lime. This quantity of water, at a meter rate of 20 cents per thousand, would cost $2\frac{1}{2}$ cents per barrel.

Equally so is it difficult to control and to account for water used if the rate is per thousand of brick laid, perch of stone laid, or yard of plaster spread. Efficient builders know this and are willing to have the water they use for building purposes metered. When the meters are not furnished by the water works, the contractor has a tested meter for such purposes. These men control a useless waste of water, and at the same time save money.

Water for building purposes is sometimes taken from adjoining premises before the owner of the new building has made application for water or before the water works has laid the new service. In cases where the neighboring premises are metered, there should be no charge on the part of the water works for the water used. The settlement should be between the owners of the premises. In adjusting the matter and making a proper charge, the owners of adjoining premises often have difficulty in controlling their tempers. The old resident believes the new resident at the beginning has overdone the neighborly act. It requires at times the services of an arbitrator or a police court judge to settle the matter.

When the adjoining premises has an unmetered supply, it sometimes requires explanations to show that the water works is entitled to compensation for the water used. The man with the service believes that he has a right to furnish water to his next-door neighbor, and both at times reason that the water is paid for once and that is sufficient. Both lose in their contention, as the charge is usually collectible of the owner of the new building.

City departments often assume the right to puddle trenches, flush streets and sewers at will. Flushing sewers is often done by plumbers and drain layers. A drain layer borrows several lengths of $2\frac{1}{2}$-in. hose from the fire department, attaches it to a convenient



TYPES OF SPRAYS AND NOZZLES TESTED.

hydrant, places the nozzle into an opening in the drain or sewer and lets the water run. These men seldom know or little care that hydrants are set primarily for fire protection and are not designed to be opened and closed by unskilled hands at random. Such use of a hydrant in one day may be more severe on the working parts of a hydrant than twenty years of legitimate use. "Fire Stream Tables" show that with 150 ft. of average $2\frac{1}{2}$-in. hose with $1\frac{1}{8}$-in. nozzle and a hydrant pressure while stream is flowing of 50 lb. per sq. in., the discharge is 192 gal. per minute. Sometimes it takes hours and sometimes days to flush a sewer. Assuming an average of two hours, the use would be about 23 000 gal., for which at 20 cents per thousand the charge should be $4.60 plus something for the wear and tear. If charges were made for this kind of service, the persons doing the work would think it excessive.

In the same line of work as flushing sewers is flushing streets. The water works is called upon to sweep the streets and gutters and then follow the sweepings into the catch basins and often clean out the blocked sewers from these sweepings by flushing. This work should be controlled by a suitable charge and by the placing of suitable flush hydrants to be used in place of fire hydrants. The water used through 150 ft. of $2\frac{1}{2}$-in. flush hose is about 11 000 gal. per hour, which at a 10-cent rate would cost $1.10 per hour per stream.

Where a water taker keeps a cow or cows and has an unmetered service, it is often convenient to have running water in the troughs for the cattle and to cool the milk. A faucet partially open runs about 10 gal. per minute, and running an hour in the morning and an hour at night uses at the 20-cent rate 24 cents worth of water per day.

A worthy special privilege is to allow the baby's night milk bottles to be kept cool and sweet from a running stream. The bottles are usually placed in a receptable and the water left running over them. Test on the flow from faucets shows that this cooling process will use water to the value of from 10 to 60 cents per night. Many a bottle of Budweiser is kept cool by use of a trickling stream, and the cooling costs the water works more than the value of the contents.

Another instance of waste is where the family goes away on a vacation and the man of the house stays at home. He sleeps at home, and if the service is on a dead end, he believes that in order to have a fresh drink of water during the night, he must turn on the faucet when he comes home and let it run all night. And it frequently happens that the water is permitted to run during the whole vacation period. This waste amounts to over 4 000 gal. in eight hours.

Many experiments have been made on the flow from orifices and nozzles, and it was thought it might interest some if the ordinary commercial sink faucets or plain bibbs were calibrated, as it were, and a few practical experiments made on discharges. Ten so-called $\frac{3}{4}$-in. sink faucets were selected. They were found to be approximately alike, but different in smoothness of bore and in the number of turns to open. The tests were made on the fractional parts of number of turns to open, that is, a $\frac{3}{4}$-in. plain bibb with an opening of $\frac{1}{16}$ of a turn flowed 2.1 gal. On full opening with $2\frac{1}{8}$ turns open, the flow was 24 gal. per minute. With a $\frac{1}{2}$-in. plain bibb and an opening of $\frac{1}{16}$ of a turn, the flow was 0.7 gal., and on $2\frac{1}{4}$ turns open the flow was 18 gal. per minute. The usual faucet opening that is commonly practiced by people who let the water run for these uncontrolled uses is from $\frac{1}{8}$ to $\frac{1}{4}$ turn. This waste is about 6.5 gal. per minute or 9 360 gal. in twenty-four hours. At 10 cents per thousand equals \$0.93 per day.

On occasions, cooling pipes take the place of the thermos bottle and the family ice chest, and this source of waste can readily use from \$1.00 to \$3.00 worth of water per day.

Sometimes disciples of Izaak Walton, men who are thrifty enough to go out to the streams and gather thousands of shiners for bait, put shiner tanks into their cellar, shed, barn, or under the piazza. They do it in a manner to keep water-works officials from knowing about it, for they know that if they pay for the water to keep the shiners alive the industry is not a paying proposition. Knowing that a meter would place a tariff on the business which would kill it, they once in a while by-pass the meter. We were able to put a meter on a shiner tank with a so-called by-pass unknown to the owner, and found that he was using water to the value of \$1.40 per day.

FIG. 1.
SPRAY BEING TESTED.

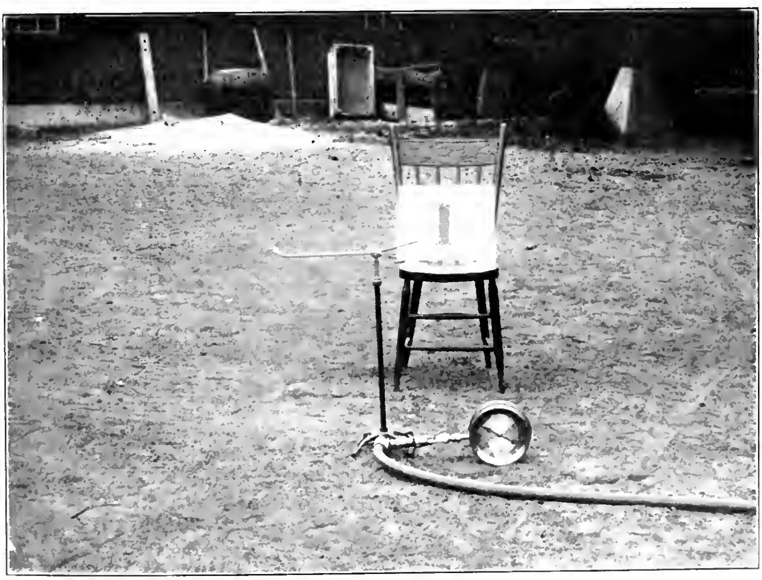


FIG. 2.
SPRAY READY FOR TEST.

Sometimes the sewing machine is run by a water motor, and the water works furnishes the family seamstress. The kitchen faucet and the degree of opening are the only guides as to what water is used. On installations of this kind, the only proper governor is a meter.

Nowadays the Monday-morning wash is done with a motorized wash tub. A water taker who paid a minimum charge of $6.00 per year objected to having a meter placed on a service which supplied the power to run a washing machine. This particular taker not only did the family washing, but took in washing. She was told that the water works was willing to furnish the water for the washing, but was not willing to do the washing. These machines are capable of using upwards of 1 000 gal. per hour.

The majority of hand-hose privileges are not abused. The persons paying for this privilege are reasonable. But there is a minority of takers in all unmetered communities who believe that in order to get value for what they pay on flat rates, they must use the hose extravagantly.

If the rule says that hand hose may be used on the premises between fixed hours of the day, the regulation is somewhat easier to enforce, especially where the police coöperate. But where the rule permits the use of hand hose a certain number of hours without specifying the exact hours, it is difficult in all cases to obtain close control. The right to use hose regardless of time limits is a common belief, and some people knowingly take advantage of the inability of a water works to have sufficient number of inspectors to keep a daily record of the hours of use. At night advantage is taken of the darkness and lack of supervision to use water on lawns and gardens indiscriminately. This abuse seems to be more prevalent with private companies than with municipal plants.

It has often been observed, when the temperature suddenly drops to freezing during the night, that the morning sun may be seen glistening on ice-covered lawns, shrubs, and plants. It is a common sight to see a fixed hose, nozzle, or spray running during a rain storm of many hours' duration.

The hose rate based on foot frontage is equally difficult to govern. In addition, it requires the checking up of frontages, while no regulation is provided for time. If hand hose only is used, it is reason-

able to suppose that this method is not so susceptible to abuse. It is a fact that some people are content to wet their lawns sufficiently to keep them in good condition, while others soak them and make them soggy.

In this era of back to the soil, when hundreds of families are practicing intensive farming and chicken raising, these pursuits require much water, and some of us realize that these minor uses of water are considerable and difficult to control.

In the rural districts supplied with water and paying but small interest returns on the cost of construction and a low minimum, means are sometimes taken to circumvent the water works by people who have large grounds or farms. The houses on these places often have the open drain pipe from the kitchen sink conveying water from the outlet through an open ditch, or arrange wooden troughs to carry the sink waste to a head ditch having laterals. During the dry period the sink faucet is kept open and the water allowed to run for long periods. Thus the water works furnishes a first-class irrigation system at low cost. One sink faucet can furnish by this means without aid of hose or pipes 25 000 gal. per day, or $5.00 worth.

Water takers will tie the hose nozzles to the back of a chair, fasten it through the handle of a garden fork, make a hitch to a wheel barrow, squeeze it into the fork of a tree, and sometimes the hose is coiled up into helix shape, the nozzle turned under and the stream or spray pointed in any direction desired.

If consumers' attention is called to these excessive uses, they will argue and interpret the rule which reads a certain number of hours per day for hand hose, that the rule means and permits a fixed spray or jet. "What difference is there between a fixed jet and a hand hose?" "Does the fixed jet, which is the same as the hand hose, use any more water?" Keeping up a rapid fire of questions, they will ask, "Do you expect me to stand or sit and hold a hand hose four hours per day, or do you want me to hire a boy for that work?" There have been cases where, rather than place a meter on the supply, they pay for the services of a boy or man to wet down, and thereby get the full privilege of the allotted hours. The reply is usually that because of the abuses of the time limit when fixed nozzles are used, it requires stricter regulations.

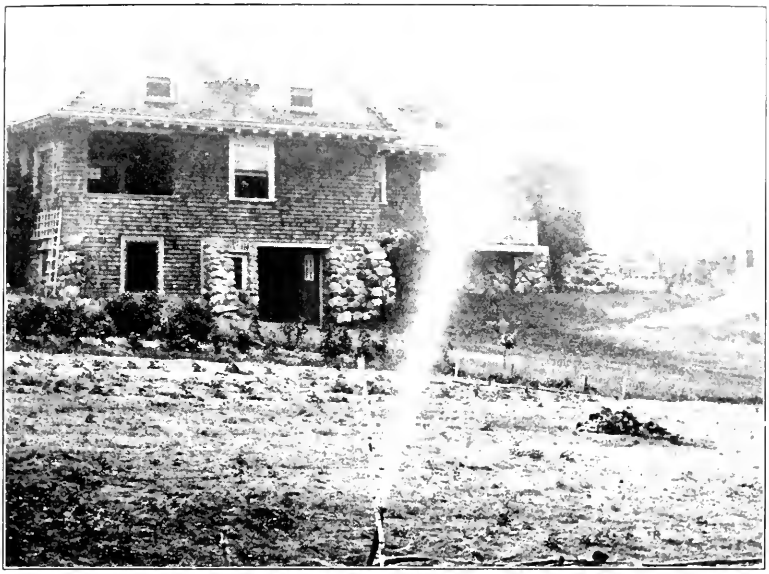


FIG. 1.
EXAMPLE OF NOZZLE FASTENED TO A STAKE.

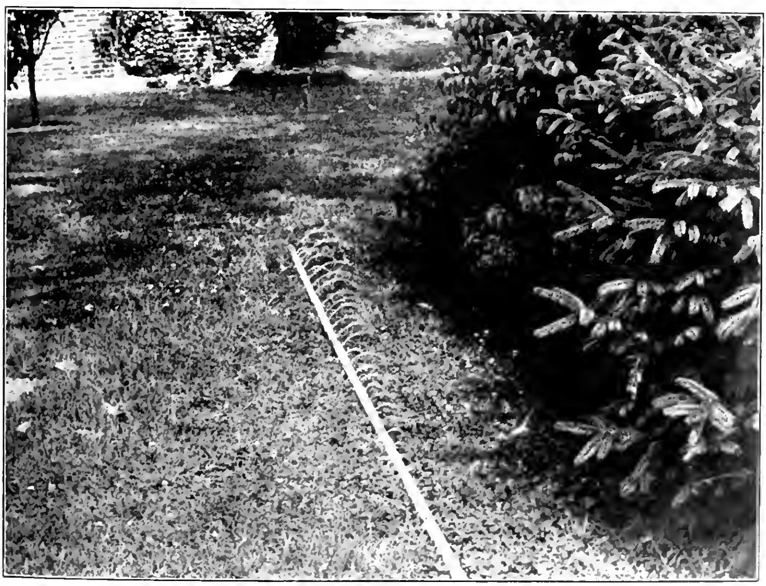


FIG. 2.
PERFORATED PIPE.

In states where public service commissions have been established, public utilities, unlike municipal plants, are not allowed to grant special privileges to cover individual cases. Private companies must not show any discrimination in rates or service. To carry out the orders of a public service commission and control the misuse of water by some, the water works is often obliged to meter fixed sprays and jets, and control by this means, the fairest and most equitable way, the use of water.

Instances are many where people permit hose streams to run night and day, week in and week out. In one case, a user paying four dollars a year for a hand-hose privilege with the right to use it four hours a day, fastened the nozzle to a block of wood and let the water run merrily on for weeks. The water works kept a record of the time and when the owner's attention was called to this misuse, she emphatically declared we were mistaken, notwithstanding that her neighbors complained that they were annoyed by the water running over the concrete walk and that the sizzling noise of the stream disturbed their slumbers. This particular misuse for twenty-four days wasted an estimated quantity of 691 200 gal.

Experiments were made on the discharge of garden hose to determine how much water a hose privilege of this kind used. Through 50 ft. of good quality $\frac{3}{4}$-in. rubber hose, at a pressure of 55 lb., and using a Boston nozzle, so-called, which has a spray attachment and a discharge orifice of 0.22 in. in diameter, the jet stream discharged 3.5 gal. per minute, while the spray attachment with a pressure of 45 lb. discharged 7 gal. per minute. The same nozzle with 25 lb. pressure discharged 2.5 gal. for the jet and 5 gal. for the spray.

The Fairy type of nozzle with an opening of .18 in. reversed the amount discharged by the jet and the spray. The jet discharged 7.5 gal. and the spray 2.5 gal. at 48 and 60 lb. pressure respectively. With a pressure of 25 lb. the jet discharged 5.5 gal. and the spray 2.0 gal. per minute.

The straight-tip type of nozzle discharged 7.5 gal. per minute at 47 lb. pressure.

The Boston type of garden hose nozzle with spray attachment discharges about 300 gal. per hour, or 7 200 gal. per day, which at

a 20-cent rate per thousand gallons, if metered, would amount to \$1.44 per day.

The Fairy type spray nozzle with jet attachment uses 240 gal. per hour, or 5 760 gal. per day, or \$1.15 worth of water at meter rates.

The ordinary straight-tip hose nozzle uses water to the value of \$2.16 in twenty-four hours. The rate of 20 cents per thousand gallons is taken because it approximates the average cost of producing 1 000 gal. of water in the United States when all the factors are figured.

Another abuse of garden hose is by people who wantonly defraud the water works by removing the nozzle and letting the open butt run on to a brown or parched spot on the lawn. An open butt of a $\frac{3}{4}$-in. hose 50 ft. in length with a sillcock pressure of 55 lb. will discharge 16.5 gal. per minute, or 23 760 gal. per day, and should give a return to the water works of \$4.75 per day.

In one instance, the discharge from such a butt was allowed to run on a brown patch with an area of a square yard for ninety-six hours. The original cost of this land was 10 cents per sq. ft., or 90 cents per sq. yd. The lawn cost about 6 cents per sq. ft. for loaming and grassing and the total cost per sq. yd. of lawn was \$1.44, while the cost of the water used for four days should be for the square yard, \$19.00, or \$2.11 per sq. ft.

Open butts are also surreptitiously allowed to run under hedges and shrubbery. Long and short lengths of perforated pipes are concealed in and under the hedges and a hose or pipe connected. One of these perforated pipes uses about 15 gal. per minute, or in a day water to the value of \$4.32, which is more than is received for a year's hose privilege.

The use of lawn and garden sprays, portable fountains, etc., has been given a great impetus in recent years in unmetered places. This increased use has come about principally by the low cost of sprinklers. The price of sprinklers ranges from 25 cents to \$5.00, and some specially designed cost more. Test of the quantity of water used by sprinklers shows that some of these low-priced tin factory sprinklers use as much water and are as effective for the purposes designed as the more expensive ones.

In a city where the water company had an abundant supply

FIG. 1.
A FORM OF SPRAY USED.

FIG. 2.
A METHOD OF COILING HOSE.

and had generally permitted the water takers for years to make the city more beautiful by furnishing water to maintain the ever green appearance of their lawns and hedges, and this with little regulation or enforcement of the rule regarding sprays, there came a time when the abuse became excessive. Conservation of resources coupled with the present-day sentiment that special privileges and discrimination should cease, brought about a change in policy. This company like others realized that the granting of special privileges for what might be termed a civic betterment, or for reasons of expediency, were illogical, and adopted the following rule:

"Premises using water for ornamental fountains, portable fountains, garden or cooling sprays, or any automatic whirling or fixed jet or nozzle on garden hose, shall be metered."

After the publication and approval of this rule by the public service commission, inspections were made, and those breaking the rule were notified. The task was to enforce this rule with a minimum friction and ill-will on the part of the water takers. A campaign of education and explanation was carried on. The company fortified itself with many photographs showing the uses and misuses of sprays. There were many humorous phases of the picture-taking, persons not knowing the real object of the photographer posed beside the broken hose or running streams.

When it became known what the object of the picture-taking was, many takers held the hose instead of using the sprinkler. In some cases water takers had to be confronted with the photographic proof and sprinkler data to be convinced that they were getting something they were not paying for.

Fifteen sprinkling devices, such as are ordinarily for sale at hardware stores, were obtained and the discharges determined.

These tests were set up so that the experiments would be conducted as nearly like the ordinary use as possible. The table of discharges from sprinklers shows the flow per minute, per hour, and per day, by these devices, also the value of the water discharged for these periods of time.

If time permitted, there could be shown the waste and uses of leaky fixtures and the deliberately continuous use of water by both self-closing and non-self-closing water closets for flushing and

TABLE SHOWING DISCHARGES FROM LAWN SPRINKLERS, PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

No.	Name.	Type.	Pressure At Sillcock.	Pressure At Nozzle.	Diameter of Inlet, Inches.	No. of Outlets.	Diameter of Outlets. Inches.	Minutes Flowing.	Total Cubic Feet.	Total Gallons.	Gallons per Min.	Length, ¾-in. Hose. Feet.	Spread of Spray. Diam. Ft.	Retail Price.	Gallons per Hour.	Gallons per Day.	Value of Water. 10c per Thousand Gallons. Per Hour.	Per Day.
1	E. S. Hotchkiss	Whirl	52	51	0.60	15	0.062	30	23	172.5	5.75	50	41	$2.50	345	8 280	$0.034	$0.828
,,	,, ,, ,,	,,	51	48	,,	,,	,,	,,	22	165.0	5.50	100	37	,,	330	7 920	0.033	0.792
,,	,, ,, ,,	,,	28	25	,,	,,	,,	,,	17	127.5	4.25	100	35	,,	255	6 120	0.025	0.612
,,	,, ,, ,,	,,	25	23	,,	,,	,,	,,	15	112.5	3.75	50	30	,,	225	5 400	0.022	0.540
2	Double Comet	Whirl and jet	57	51	0.62	1–3–49	0.142 0.080 0.036	15	13	97.5	6.5	50	56	5.00	390	9 360	0.039	0.936
,,	,, ,,	,,	30	25	,,	,,	,,	,,	12	90.0	6.0	50	50	,,	360	8 640	0.036	0.864
,,	,, ,,	,,	57	50	,,	,,	,,	,,	11	82.5	5.5	100	45	,,	330	7 920	0.033	0.792
,,	,, ,,	,,	33	25	,,	,,	,,	,,	8	60.0	4.0	100	43	,,	240	5 760	0.024	0.576
3	Crescent	Whirl	48	25	0.62	15 15	0.062 0.072	15	20	150.0	10.0	100	40	.....	600	14 400	0.060	1.440
,,	,,	,,	43	24	,,	,,	,,	,,	18	135.0	9.0	100	37	.....	540	12 960	0.054	1.296
,,	,,	,,	49	34	,,	,,	,,	,,	19	142.5	9.5	50	40	.....	570	13 680	0.057	1.368
,,	,,	,,	41	25	,,	,,	,,	,,	17	127.5	8.5	50	38	.....	510	12 240	0.051	1.224
4	No Name	Whirl	53	41	0.61	15	0.070	15	16	120.0	8.0	50	42	1.25	480	11 520	0.048	1.152
,,	,, ,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	50	38	,,	390	9 360	0.039	0.936
,,	,, ,,	,,	54	42	,,	,,	,,	,,	14	105.0	7.0	100	41	,,	420	10 080	0.042	1.008
,,	,, ,,	,,	33	25	,,	,,	,,	,,	10	75.0	5.0	100	39	,,	300	7 200	0.030	0.720
5	No Name	Whirl	55	42	0.60	15 2	0.062 0.055	15	15	112.5	7.5	100	44	.....	450	10 800	0.045	1.080
,,	,, ,,	,,	35	25	,,	,,	,,	,,	11	82.5	5.5	100	41	.....	330	7 920	0.033	0.792
,,	,, ,,	,,	53	47	,,	,,	,,	,,	15	112.5	7.5	50	44	.....	450	10 800	0.045	1.080
,,	,, ,,	,,	34	25	,,	,,	,,	,,	11	82.5	5.5	50	41	.....	330	7 920	0.033	0.792
6	No Name	Whirl	56	49	0.60	11 2	0.061 0.055	15	13	97.5	6.5	50	46	.....	390	9 360	0.039	0.936
,,	,, ,,	,,	30	25	,,	,,	,,	,,	8	60.0	4.0	50	44	.....	240	5 760	0.024	0.576
,,	,, ,,	,,	55	44	,,	,,	,,	,,	12	90.0	6.0	100	42	.....	360	8 640	0.036	0.864
,,	,, ,,	,,	35	25	,,	,,	,,	,,	8	60.0	4.0	100	39	.....	240	5 760	0.024	0.576

7	Hotchkiss	Whirl	50	30	0.41	52 / 15	0.041 / 0.056	15	18	135.0	9.0	100	37	.....	540	12 960	0.054	1.296
,,	,,	,,	43	25	,,	,,	,,	,,	16	120.0	8.0	100	34	.....	480	11 520	0.048	1.152
,,	,,	,,	48	44	,,	,,	,,	,,	19	142.5	9.5	50	42	.....	570	13 680	0.057	1.368
,,	,,	,,	37	25	,,	,,	,,	,,	16	120.0	8.0	50	36	.....	480	11 520	0.048	1.152
8	Hotchkiss	Whirl	55	47	0.41	15	0.056	15	13	97.5	6.5	50	38	.....	390	9 360	0.039	0.936
,,	,,	,,	32	25	,,	,,	,,	,,	10	75.0	5.0	50	36	.....	300	7 200	0.030	0.720
,,	,,	,,	55	46	,,	,,	,,	,,	11	82.5	5.5	100	36	.....	330	7 920	0.033	0.792
,,	,,	,,	36	25	,,	,,	,,	,,	8	60.0	4.0	100	34	.....	240	5 760	0.024	0.576
9	No Name	Fixed	46	31	0.52	60	0.040	15	22	165.0	11.0	50	40	0.85	660	15 840	0.066	1.584
,,	,, ,,	,,	40	25	,,	,,	,,	,,	20	150.0	10.0	...	36	,,	600	14 400	0.060	1.440
,,	,, ,,	,,	47	27	,,	,,	,,	,,	21	157.5	10.5	100	38	,,	630	15 120	0.063	1.512
,,	,, ,,	,,	46	25	,,	,,	,,	,,	19	142.5	9.5	100	35	,,	570	13 680	0.057	1.368
10	Hotchkiss	Whirl	54	49	0.42	15	0.055	15	13	97.5	6.5	50	41	1.00	390	9 360	0.039	0.936
,,	,,	,,	30	25	,,	,,	,,	,,	9	67.5	4.5	50	36	,,	270	6 480	0.027	0.648
,,	,,	,,	56	48	,,	,,	,,	,,	12	90.0	6.0	100	38	,,	360	8 640	0.036	0.861
,,	,,	,,	36	25	,,	,,	,,	,,	8	60.0	4.0	100	35	,,	240	5 760	0.024	0.576
11	Hotchkiss	Fixed	54	45	0.42	50	0.032	15	16	120.0	8.0	50	38	1.00	480	11 520	0.048	1.152
,,	,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	50	34	,,	390	9 360	0.039	0.936
,,	,,	,,	54	41	,,	,,	,,	,,	15	112.5	7.5	100	36	,,	450	10 800	0.045	1.080
,,	,,	,,	33	25	,,	,,	,,	,,	13	97.5	6.5	100	34	,,	390	9 360	0.039	0.936
12	No Name	Fixed	52	39	0.41	50	0.035	15	17	127.5	8.5	100	37	0.75	510	12 240	0.051	1.224
,,	,, ,,	,,	36	25	,,	,,	,,	,,	14	105.0	7.0	100	33	,,	420	10 080	0.042	1.008
,,	,, ,,	,,	52	41	,,	,,	,,	,,	17	127.5	8.5	50	39	,,	510	12 240	0.051	1.224
,,	,, ,,	,,	35	25	,,	,,	,,	,,	14	105.0	7.0	50	34	,,	420	10 080	0.012	1.008
13	Little Wonder	Fixed	54	49	0.40	1	0.32	15	12	90.0	6.0	50	36	0.25	360	8 640	0.036	0.864
,,	,, ,,	,,	30	25	,,	,,	,,	,,	8	60.0	4.0	50	28	,,	240	5 760	0.024	0.576
,,	,, ,,	,,	53	44	,,	,,	,,	,,	11	82.5	5.5	100	34	,,	330	7 920	0.033	0.792
,,	,, ,,	,,	31	25	,,	,,	,,	,,	8	60.0	4.0	100	27	,,	240	5 760	0.024	0.576
14	Niagara	Fixed	52	41	0.60	48	0.035	15	15	112.5	7.5	100	38	0.35	450	10 800	0.045	1.080
,,	,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	100	35	,,	390	9 360	0.039	0.936
,,	,,	,,	53	44	,,	,,	,,	,,	15	112.5	7.5	50	38	,,	450	10 800	0.045	1.080
,,	,,	,,	32	25	,,	,,	,,	,,	13	97.5	6.5	50	36	,,	390	9 360	0.039	0.936
15	Hero	Fixed	55	46	0.62	56	0.038	15	15	112.5	7.5	50	36	0.50	450	10 800	0.045	1.080
,,	,,	,,	34	25	,,	,,	,,	,,	11	82.5	5.5	50	31	,,	330	7 920	0.033	0.792
,,	,,	,,	56	45	,,	,,	,,	,,	14	105.0	7.0	100	33	,,	420	10 080	0.042	1.008
,,	,,	,,	33	25	,,	,,	,,	,,	10	75.0	5.0	100	30	,,	300	7 200	0.030	0.720

TABLE SHOWING DISCHARGES FROM GARDEN HOSE NOZZLES, PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

No.	Name	Type.	Pressure. At Sillcock.	Pressure. At Nozzle.	Diameter of Inlet.	No. of Outlets.	Diameter of Outlets.	Minutes Flowing.	Total Cubic Feet.	Total Gallons.	Gallons per Minute.	Length ¾-in. Hose. Ft.	Horizontal Stream, no allowance for wind. Ft.	Retail Price.	Gallons per Hour	Gallons per Day	Value of Water 10c per Thousand Gallons. Per Hour.	Value of Water 10c per Thousand Gallons. Per Day.
16	Boston	Jet	60	55	0.563	1	0.22	15	7.0	52.5	3.5	50	45	$0.40	210	5 040	0.021	0.504
,,	,,	Spray	55	45	,,	,,	,,	,,	14.0	105.0	7.0	50	18	,,	420	10 080	0.042	1.008
,,	,,	Jet	30	25	,,	,,	,,	,,	5.0	37.5	2.5	50	37	,,	150	3 600	0.015	0.360
,,	,,	Spray	30	25	,,	,,	,,	,,	10.0	75.0	5.0	50	14	,,	300	7 200	0.030	0.720
,,	,,	Jet	60	55	,,	,,	,,	,,	7.0	52.5	3.5	100	45	,,	210	5 040	0.021	0.504
,,	,,	Spray	55	45	,,	,,	,,	,,	14.0	105.0	7.0	100	18	,,	420	10 080	0.042	1.008
,,	,,	Jet	30	25	,,	,,	,,	,,	5.0	37.5	2.5	100	37	,,	150	3 600	0.0150	0.360
,,	,,	Spray	32	25	,,	,,	,,	,,	11.0	82.5	5.5	100	18	,,	330	7 920	0.033	0.792
17	Fairy	Jet	57	48	0.600	1	0.18	15	15.0	112.5	7.5	50	47	0.50	450	10 800	0.045	1.080
,,	,,	Spray	65	60	,,	,,	,,	,,	5.0	37.5	2.5	50	10	,,	150	3 600	0.015	0.360
,,	,,	Jet	31	25	,,	,,	,,	,,	11.0	82.5	5.5	50	30	,,	330	7 920	0.033	0.792
,,	,,	Spray	30	25	,,	,,	,,	,,	4.0	30.0	2.0	50	6	,,	120	2 880	0.012	0.288
,,	,,	Jet	57	45	,,	,,	,,	,,	15.0	112.5	7.5	100	46	,,	450	10 800	0.045	1.080
,,	,,	Spray	61	59	,,	,,	,,	,,	6.0	45.0	3.0	100	10	,,	180	4 320	0.018	0.432
,,	,,	Jet	33	25	,,	,,	,,	,,	11.0	82.5	5.5	100	40	,,	330	7 920	0.033	0.792
,,	,,	Spray	28	25	,,	,,	,,	,,	4.0	30.0	2.0	100	6	,,	120	2 880	0.012	0.288
18	No Name	Jet	56	47	0.630	1	0.20	15	15.0	112.5	7.5	50	56	0.75	450	10 800	0.045	1.080
,,	,, ,,	Jet	31	25	,,	,,	,,	,,	11.0	82.5	5.5	50	39	,,	330	7 920	0.033	0.792
,,	,, ,,	Jet	56	45	,,	,,	,,	,,	15.0	112.5	7.5	100	54	....	450	10 800	0.045	1.080
,,	,, ,,	Jet	33	25	,,	,,	,,	,,	11.0	82.5	5.5	100	46	.....	330	7 920	0.033	0.792

Table showing Flow of Sink Faucets, Pennichuck Water Works, Nashua, N. H.
September 1, 1914.

Plain Bibbs or Sink Faucets.					Average Pressure.		Gallons per Minute Flowing.												
Name.	Nominal Size of Faucet. Inches.	Diam. of Inlet. Inches.	Diam. of Outlet. Inches.	Total No. of Turns.	Static.	With Stream Flowing.	$\frac{1}{16}$ Turn.	$\frac{1}{8}$ Turn.	$\frac{1}{4}$ Turn.	$\frac{1}{2}$ Turn.	$\frac{3}{4}$ Turn.	1 Turn.	$1\frac{1}{4}$ Turns.	$1\frac{1}{2}$ Turns	$1\frac{3}{4}$ Turns	2 Turns	$2\frac{1}{8}$ Turns	$2\frac{1}{4}$ Turns	$2\frac{1}{2}$ Turns
Mueller Standard	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$2\frac{1}{8}$	63	59	2.1	5.4	7.1	11.5	19.0	22.3	23.0	23.2	23.5	23.8	21.1		
" "	"	"	"	"	61	56	2.0	5.1	7.0	11.2	18.6	21.9	22.5	23.1	23.3	23.5	23.8		
Mueller Extra	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$2\frac{1}{2}$	57	53	0.7	3.9	9.7	12.6	15.3	17.7	18.1	18.2	18.2	18.3	18.1	18.6	19.0
" "	"	"	"	"	58	54	0.8	1.0	10.3	12.8	15.5	18.6	18.2	18.2	18.2	18.6	18.6	18.7	19.0

to prevent freezing. There are so many and so varied small uses difficult to control that at this time it is the intention to mention only a few, and trust that a discussion will bring out others and by this means reveal to some of us uses, misuses, and abuses which we have not considered of much importance in the past.

The remedy for these abuses has been applied in those places which have adopted either universal metering or metering supplies which abuse the service privilege.

A further remedy which has been suggested to assist water-works managers to put their plants on a businesslike and practical basis would be the placing of municipal water works under the same supervision by state public service commissions as other public service corporations, for, after all is said, the municipal corporation has the same need of supervision as the private corporation. In the thickly settled portions of the country the end must come to continued extensions of water-collecting areas, and a broad and far-seeing control of wastes will do much to settle this most serious problem with which we are confronted.

FLOW OF OPEN BUTT, $\frac{3}{4}$-IN. GARDEN HOSE ATTACHED TO $\frac{3}{4}$-IN. SILLCOCK (PRESSURE AT SILLCOCK, 55 POUNDS), PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

Sillcock Open in Turns.	Gallons per Minute.	Gallons per Hour.	Gallons per Day.	Value of Water.			
				10c per Thousand Gals.		20c per Thousand Gals.	
				Per Hour.	Per Day.	Per Hour.	Per Day.
$\frac{1}{4}$	6.75	405	9 720	0.040	0.972	0.080	1.944
$\frac{1}{2}$	8.25	495	11 880	0.049	1.188	0.098	2.376
$\frac{3}{4}$	9.00	540	12 960	0.054	1.296	0.108	2.592
1	13.50	810	19 440	0.081	1.944	0.162	3.888
$1\frac{1}{4}$	15.00	900	21 600	0.090	2.160	0.180	4.320
$1\frac{1}{2}$	16.00	960	23 040	0.096	2.304	0.192	4.608
$1\frac{3}{4}$	16.50	990	23 760	0.099	2.376	0.198	4.752
2	16.50	990	23 760	0.099	2.376	0.198	4.752
3	16.50	990	23 760	0.099	2.376	0.198	4.752
4	16.50	990	23 760	0.099	2.376	0.198	4.752
$4\frac{3}{4}$	16.50	990	23 760	0.099	2.376	0.198	4.752

DISCUSSION.

Mr. W. C. Hawley. Mr. President, I had a gentleman in my office, some time ago, objecting strenuously to a large bill for water supplied by meter. I explained the working of the meter and he was very decent about it and said he would investigate. He came back a few days later with a check for the amount of his bill and he explained, — "I went over to the house on Saturday afternoon and those blanked Hunkies had a keg of beer in the bathtub with the water running, getting it cool for Sunday."

I have some trouble on hand now that is a little different from anything Mr. Sullivan has mentioned. Perhaps some of the gentlemen here can help me toward its solution. A meter reader, some two or three months ago, reported a case where a meter read less at that time than it did three months before. An investigation showed that the seal on the meter had been broken, but the meter was on the pipe in the right position. We took the meter off and found decided evidence of wear on the end of the driving bar opposite to where it should have been, which seemed to indicate that that meter had been reversed and had then been put back in the right position. That house was one of a row of ten, I believe, and we took off three other meters in that row whose records seemed to indicate something peculiar in the consumption of the water. We found that those three showed the same indication of having been run backward as the first. The gentleman who owned those houses had several others, and we took off, I think, twelve meters supplying his houses. The other houses were vacant and we could not get the meters. All but one of those meters when examined showed evidence of the meters having been run backward although they were all in right when we took them off. Now I can't say positively that those meters had been reversed. We did not find them reversed, but there are the facts. That man has one son who is a plumber and one who is a lawyer, so you see what I am up against. I should like to know if any of the members have had similar experiences in the matter of evidence of reversed meters. We have only found a very few similar cases. We have been watching now for a couple of months, and we have had but two or three

meters come in that have indicated anything of that kind in that time. It has occurred to me that possibly if there was a pocket of air in the pipe when the water was shut off it might drive the disk back, and in that case might make a mark on the driving bar. Whether or not that is so, I do not know.

Mr. Francis T. Kemble. Mr. Hawley, I can give an answer to that. About five years ago I had an experience of that kind: I had five meters, all in houses owned by one man, that showed almost no registration. We watched them, and ultimately we found two of them reversed. The others were never reversed, but showed a low registration. After finding the first ones reversed, all these meters were sealed. We found that to beat us it was simply a matter of taking out the screws, removing the registering gear, and backing it up. We beat that by putting sealing wax over the screws, on which we use the Company seal. We have followed this practice with all our meters for the last few years, and have had no further trouble.

Mr. James A. McMurray. I may say that in Boston we have experienced the same difficulty and we are quite satisfied that meters have been tampered with. At the present time there is a group of meters on premises owned by one individual in a certain section of Boston which have been giving us much annoyance. The owner of the properties has come into the office to complain about the size of the bills, despite the fact that some of the meters were set backwards. Since the visit of the owner we have sealed some of the meters, and upon a recent inspection we found that the meters had been reversed, showing that this was undoubtedly done after deliberation. I am satisfied that in some instances meters have been deliberately smashed when the registration was increasing.

Unless some statute is passed that will enable the cities and towns to stop this sort of thing, I do not think we can stop it. City and town ordinances appear to be of no avail. The present legislature has passed a statute placing the responsibility to a certain extent upon the owner, but the law department says that we must show that the owner or his agent was aware of the damage done to the meter.

Another point in connection with small registration: In a certain

part of Boston recently annexed, a trick was employed by a certain group of citizens who raised vegetables in small quantities. Instead of setting the meter backwards they have taken the screws off and taken the clock out, and, of course, while they were using water on the farm there was no registration. When they ceased using water the clock was dropped back into position and when the meter reader again visited the premises the registration, of course, was progressing. We suspected that something was wrong and after careful watch we found the above-mentioned condition. We are satisfied that it is impossible to have a meter register backwards unless the meter is actually so set.

There is another difficulty that we have met. If you examine a round dial clock very carefully you will see that you can readily detach the hands and adjust them to any reading you desire and at the same time have the hands continue to register as if nothing had been done to them. There were two or three houses in Boston where we suspected this condition on account of small registration. The repair department went to these buildings and took the clocks off, and upon careful scrutiny found the conditions as above mentioned. Of course, any reading could be had by any owner who employed that method to cheat the city. The only thing to do, as the gentleman has said, is to seal all meters in the section where trouble is expected. But in the absence of some effective law the sealing is of little avail if we cannot place the responsibility upon the individual.

Mr. Hawley. These meters were set a number of years ago before we used the sealing nuts on the inlet side of the meter. Some of them have been sealed since, but they were not all sealed. However, the screws on the register boxes were sealed. For some years past, we have been sealing all our meters with a twisted copper wire and lead seal, sealing both the inlet nut and also the screws on the registers. In the future, we shall seal both inlet and outlet nuts; but these meters, if tampered with, were reversed.

I had a case of that kind a couple of years ago, where a former employee of our water company, an Italian, that we might have supposed would be incapable of such a thing, reversed his meter without taking the seal off. He got all the slack he could in the

wire, loosened the nut one-eighth of a turn, backed the swivel out, and turned the meter around. He got a little too much to the good and his meter read less than on the previous reading. We studied the thing and finally decided how it had been done, and sent for him. I made the bill large enough to cover all the water he could have taken and added something to it and threatened him with prosecution, and he settled up. I have had two or three experiences of that kind. But if anything was done in this case I mentioned it was reversing the meter, and that is indicated by the wear on the other end of the driving bar of the intermediate gear.

Mr. McMurray. It just occurred to me that at the present time we are considering a case quite similar to the one Mr. Hawley has brought out. It may be that the sixth hand is stuck. Three months ago the register of the meter was 671 000. Two months since the meter reads 650 odd thousand. We didn't know what to do about that case, and after a preliminary inspection when everything appeared to be right we felt that the meter was probably stuck, and that it should be 750 000.

REPORT OF COMMITTEE ON YIELD OF DRAINAGE AREAS.

[*Read September 9, 1914.*]

CONTENTS.

To the New England Water Works Association:

Gentlemen, — On February 8, 1911, the Executive Committee of the Association, after considering a communication from Mr. C. E. Chandler, voted:

"That the President be and hereby is authorized to appoint a suitable committee to investigate the yields of New England watersheds and such other watersheds as the committee may deem desirable during the present dry period."

In accordance with this vote, a committee of nine was soon appointed by the President, and the number was subsequently increased to ten. The committee held its first meeting on March 8, 1911, and discussed at length the scope of the work of the committee and the nature of the inquiries which should be made in order to obtain the desired information.

It was soon found that the year 1911 was likely to be drier than the three preceding years, and that in order to make a satisfactory report the committee would necessarily have to wait for the records of that year. These records were not all received until January, 1913.

In western New England and in New York the drought was temporarily terminated by excessive rainfalls in the autumn of 1911, but in the central and eastern part of Massachusetts the low yield of the streams continued throughout 1912 and 1913, and also in 1914 to the time of making this report.

The remarkably dry period which has existed in central Massachusetts in the last six years is well shown by the records of the yield of the Wachusett drainage area, as follows:

TABLE 1.

Yield of Wachusett Drainage Area.

Year.	Yield in Gal. per Day per Sq. Mile.	Year.	Yield in Gal. per Day per Sq. Mile.
1897	1 253 000	1908	847 000
1898	1 551 000	1909	918 000
1899	1 051 000	1910	828 000
1900	1 264 000	1911	682 000
1901	1 507 000	1912	891 000
1902	1 248 000	1913	879 000
1903	1 285 000		
1904	1 025 000		
1905	926 000		
1906	1 043 000		
1907	1 180 000		
Averages,	1 212 000		841 000

It will be noted that the highest yield during the past six years is a little less than the lowest yield during the preceding eleven years, and that the average during the last six years is but little more than two thirds of the average during the preceding period. Owing to the construction and filling of the Wachusett Reservoir during the years 1904–1907, the per cent. of drainage area covered with water increased from an average of 3.1 in the first group of years to an average of 6.9 in the second group, and the consequent increase of evaporation accounts for a small part of the decrease in the yield of the later group of years.

GENERAL STATEMENT.

In general water-works practice, the yield of a drainage area — often called the "run-off" — is obtained by measuring the quantity of water drawn for consumption, adding to it the quantity running over the dam of the storage reservoir or otherwise wasted, and then making an addition or subtraction, as the case may be, for the amount of water added to or drawn from storage. The result is approximately the natural flow of the stream as it would be if the storage reservoir did not exist.

In the great majority of cases this approximation is sufficiently accurate for practical purposes, but when the best results are

desired there are other features which should be considered in order to make the records of yield obtained from certain drainage areas applicable to others.

Your committee has endeavored to make the correction which is as a rule the most important one, namely, that required to take account of the extent of the water surface upon a drainage area. Where a considerable proportion of an area consists of water surfaces, the evaporation causes the yield of the drainage area to be materially less, especially in the summer months, than if such water surfaces did not exist. Therefore, it is desirable, where accuracy is required, to divide the drainage area into land surfaces and water surfaces and consider the yield of each separately.

Swamps have water standing in them part of the year, and present damp surfaces much of the year, and may, therefore, be considered as intermediate between the upland from which the evaporation is least and the water surfaces from which the evaporation is greatest.

There are other corrections which it would be desirable to make but which cannot be made because the necessary data are lacking. For instance, in the case of large rivers like the Merrimack and Connecticut, it is not feasible to make corrections for the water drawn from or added to storage in the various reservoirs and mill ponds upon their drainage areas. Hence, the measured flow of such streams is not exactly the natural flow. The difference, however, is small except in the drier portions of the year, when the measured flow may be considerably more than the natural flow, and such streams cannot be used for deducing accurately the yield in dry times of drainage areas without storage.

Under ordinary conditions, when the correction is made for water added to or drawn from a storage reservoir, the correction covers only the visible storage and not the storage in the interstices of the ground around the reservoir. It is generally impracticable to include this feature in the computations. As a rule, the amount of such invisible storage is small in comparison with the visible storage, but it may be large enough to materially affect the deduced natural yield of a drainage area in dry months.

On a drainage area where proper correction is made for storage in the reservoirs under the control of the water authorities, there

are in some places other small reservoirs not under such control which are not included when making the corrections for storage.

In some instances, water is diverted from or into a drainage area in connection with systems of water supply and sewerage, and such diverted water is generally taken into account in preparing the records, but there is frequently some percolation or leakage past a dam, or through the natural barriers which retain a lake or reservoir, of which no account is taken.

The committee has endeavored to show in each case the extent to which the measured yield of the drainage areas has been corrected for these various reasons.

INFORMATION ASKED FOR.

In order to obtain the necessary information regarding the yield of drainage areas, a series of questions accompanied by blank forms, suggestions, and explanations was sent to water works superintendents and others who had records of the flow of streams in and near New England.

Sheet A was as follows:

SHEET A.

New England Water Works Association.
Committee on Yield of Drainage Areas.

Data regarding Drainage Area of the

Submitted by —

(a) Name of stream or drainage area?

(b) Location of point where yield is measured?

(c) Area of drainage area, including water surfaces?

(d) Area of water surfaces of reservoirs of known size?

(e) Estimated area of water surfaces of other reservoirs, ponds, and streams?

(f) Estimated area of swamps —

Drained?
Undrained?
Total?

(g) To what extent is the measurement of run-off corrected for water drawn from or added to storage?

(h) In your judgment, is there any considerable amount of storage in the ground surrounding the reservoirs which becomes available as the water is drawn down? And can you give an estimate of the amount?

(i) Have you made any allowance for such invisible storage in your records of run-off?

(j) Is there any percolation, leakage, or diversion of water into or out of the drainage area which may materially affect the records of run-off?

(k) Character of drainage area? (As to slopes, kind of soil, to what extent forested, amount of storage in ground, etc.?)

(l) What is the run-off and rainfall for the years 1908, 1909, 1910, and 1911? (Please give these answers on the accompanying blank forms.)

(m) If you have earlier records of run-off from your drainage area lower or nearly as low as the records of 1908–1911, please give them on the blank forms.

(n) Method used in making measurements of run-off, and probable degree of accuracy.

(o) What kind of rain gages are used and how located? How is the snowfall measured and recorded?

(p) Note any changes in conditions of either drainage area or reservoirs that have taken place during the time that the yield of the drainage area has been measured, giving date of all changes.

(q) Give any additional information that may be of value in regard to the yield of this drainage basin.

Sheet B was a blank for recording the results for each year, as follows.

Sheet B.

New England Water Works Association — Committee on Yield of Drainage Areas.

Yield of the For the Year Drainage Area, Square Miles.

(1) Month.	(2) Drawn for Consumption.	(3) Overflow and Waste.	(4) Gain (+) or Loss (−) of Storage.	(5) Total Yield of Drainage Area.	(6) Gain or Loss Due to Water Surfaces.	(7) Total Yield of Land Surface.	(8) Yield per Square Mile of Drainage Area.	(9)	(10) Yield per Square Mile of Land Surface.	(11)	(12) Precipitation on Drainage Area. Inches.	(13) Precipitation Collected on Basis of Col. (5). Inches.	(14) Per Cent. of Precipitation Collected.
	Yield of Drainage Area. Million Gallons.						Gallons per Day.	Cubic Feet per Second.	Gallons per Day.	Cubic Feet per Second			
Jan.													
Feb.													
March													
April													
May													
June													
July													
August													
Sept.													
Oct.													
Nov.													
Dec.													
The Year													

For explanation of column headings see Sheet D. Give daily or weekly yield during the driest one, two, or three months, where practicable, **placing results on Sheet C.**

Sheet C was arranged for recording the data for the [illegible] driest period of one, two, or three months, and is not reproduced.

Sheet D served as an explanation of Sheets B and C, as follows:

SHEET D.

New England Water Works Association.
Committee on Yield of Drainage Areas.

Suggestions and explanations regarding the preparation of data for Sheets B and C.

Object of Sheets B and C.

It is intended to have compiled on Sheets B and C data on the yield of a single drainage basin for one year, giving information as indicated in the various column headings as far as available, and as explained further below.

Explanation of Column Headings, Sheet B.

Column 1 requires no explanation.

Column 2 gives for each month the total amount of water in million gallons drawn from reservoir (or other source of supply) and used for consumption.

Column 3 gives for each month the total amount of water in million gallons overflowing at the reservoir or wasting in any other way. The sum of Columns (2) and (3) represents the total amount of water actually leaving or passing by the reservoir each month.

Column 4 gives for each month the gain (—) or loss (—) of storage in million gallons corresponding to any rise or fall of water level and consequent change in quantity of water being held in any ponds or reservoirs on the stream.

Column 5 gives for each month, in million gallons, the total yield of the drainage area at the reservoir outlet corrected for any change in quantity of water stored. It is obtained by summing the results in Columns (2), (3), and (4), the latter being taken as — when there has been an **increase** in stored water during the month and as — when there has been a **decrease** in stored water. The results in Column (5) represent practically the water running into the reservoir (or reservoirs) as reduced by evaporation from reservoir **surface** and as increased by rainfall upon reservoir surface. If there is no storage in the drainage basin, Column (4) would be left blank and Column (5) would be simply the sum of Columns (2) and (3).

Column 6 gives for each month, in million gallons, the gain or loss due to the difference between the rainfall upon and the evaporation from the water surfaces. In determining the gain or loss, take into account the diminished area of water surfaces as the reservoirs are drawn down; and to provide for the excess of evaporation from the swamps over the evaporation from the upland.

include with the water surfaces 30 per cent.of the area of drained swamps and 40 per cent. of the area of the undrained swamps.

For the amount of evaporation (unless you have data more applicable to the situation), use the mean monthly evaporation as given by Mr. Desmond FitzGerald in his paper on Rainfall, Flow of Streams, and Storage, Trans. of Amer. Soc. of Civil Engrs., Sept., 1892, p. 275, as given below.

Each inch of difference between the evaporation and the rainfall is equivalent to 27 154 gallons per acre and to 17 379 000 gallons per square mile.

EVAPORATION.

Month.	Inches.
January	0.96
February	1.05
March	1.70
April	2.97
May	4.46
June	5.54
July	5.98
August	5.50
September	4.12
October	3.16
November	2.25
December	1.51
	39.20

Column 7 gives for each month, in million gallons, the total yield of land surface alone in the drainage area obtained by subtracting (or adding) the results in Column (6) to those in Column (5). Column (6) will be subtractive when evaporation from reservoir surface is **less** than rainfall upon it; Column (6) will be additive when evaporation from reservoir surface **exceeds** rainfall. Column (7) thus represents the yield of **land surface alone.**

Columns 8 and 9 give for each month the yield per square mile of the drainage area in gallons per day and cubic feet per second, computed from the results in Column (5) as a basis. Columns (8) and (9) therefore represent **unit** yield as regards the entire drainage area, including water surface.

Columns 10 and 11 give for each month values of unit yield similar to those in Columns (8) and (9) but based upon the results in Column (7). Columns (10) and (11) therefore represent unit run-off from the drainage area as regards land surface **only.**

If data are not available to compute Columns (6) and (7), Columns (10) and (11) will of course be omitted.

Column 12 gives, for each month, the precipitation on the drainage area, in inches.

The location of the rain gage stations that are used in the determination of precipitation on the drainage area should be noted on Sheet A under (o).

What is desired in Column (12) is the **average** precipitation over the whole drainage basin, and if the figures of precipitation are not believed to be truly representative of the basin as a whole, this should be stated on Sheet A, under (o), and any additional information given that will be helpful in estimating the true **average** precipitation.

Column 13 gives for each month the precipitation collected or the run-off from the drainage basin expressed in inches depth over the entire basin, based on the results given in Column (5).

Column 14 is obtained by dividing Column (13) by Column (12) and multiplying by 100.

Partially Complete Data.

In many cases it will not be possible with information at hand to fill in all the columns on Sheet B. In such cases, information should be given as far as available. The committee will be glad to complete any sheets where this is simply a matter of computation, but should be supplied with all necessary base data.

Additional Data to be placed on Sheet C.

In addition to the results called for by Sheet B, it is desired by the committee to obtain daily or weekly records of yield during the very dry period. These should be given for the driest one, two, or three months, and can be placed upon Sheet C, with appropriate notes.

In answer to the inquiries made, returns were received of the yields of twenty-two drainage areas, as follows:

Drainage Area.	Period Covered.
Maine.	
Sebago Lake	1908–1911
New Hampshire.	
Connecticut River at Orford, N. H.	1908–1911
Massachusetts.	
Connecticut River at Sunderland, Mass.	1908–1911
Deerfield River at Shelburne Falls, Mass.	1908–1911
Merrimack River at Lawrence, Mass.	1908–Mar., 1912, inc.
Cambridge Water Works, Stony Brook	1908–Feb., 1912, inc.
Holyoke Water Works, Manhan River	1899, 1900, 1908–1911
Metropolitan Water Works:	
Wachusett Reservoir	1908–1914
Sudbury River	1879–1884, inc., 1908–Feb., 1912, inc.
Lake Cochituate	1908–1912
Springfield Water Works:	
Borden Brook	1910–Oct., 1912, inc.
Westfield Little River	1908–1911

Drainage Area.	Period Covered.
Westfield Water Works, Tillotson Brook	1908–1911
Worcester Water Works, Tatnuck Brook	1908–Feb., 1912, inc.
Rhode Island.	
Pawtucket Water Works, Abbott Run	1908–1912
Connecticut.	
Hartford Water Works, Hartford Reservoirs	June, 1909–1912
Norwich Water Works, Fairview and Meadow Brooks	1910–1912
Waterbury Water Works, West Branch of Naugatuck River	1908–1912
New York.	
New York Water Works:	
Croton River	June, 1879–1883, 1908–1913
Esopus Creek	1908–1913
Rondout Creek	1908–1911
Schoharie Creek	1908–1911

YIELD FROM WATER SURFACES.

As already indicated, the actual measurements of the yield of a drainage area necessarily cover both land and water surfaces. It is desirable to deduce the yield of the land surface. In order to do this, it is necessary to determine first the yield of the water surfaces. Such a yield in any given period is the difference between the precipitation on the water surfaces and the evaporation therefrom. It is sometimes a plus quantity and sometimes a minus quantity, depending upon whether the precipitation is greater or less than the evaporation.

The amount of precipitation is easily determined from some neighboring gage, but the actual determination of evaporation is a very difficult matter, so that as a substitute for the actually measured evaporation the results of careful experiments made elsewhere are generally used. This can be done without serious error, because the evaporation for a given month in different years does not vary very much.

The committee has used, for the purpose of determining the yield of water surfaces, the results of the careful and extended experiments upon evaporation made by Mr. Desmond FitzGerald, member of the Association, given in his paper on "Rainfall, Flow of Streams, and Storage," in Transactions of American Society of Civil Engineers, September, 1892, page 275, as follows:

TABLE 2.

EVAPORATION FROM WATER SURFACES.

Month.	Average Temperature of Water in Degrees Fahrenheit.	Evaporation in Inches.
January	32.8	0.96
February	32.4	1.05
March	36.4	1.70
April	46.5	2.97
May	58.6	4.46
June	67.9	5.54
July	72.3	5.98
August	71.3	5.50
September	65.6	4.12
October	53.6	3.16
November	42.8	2.25
December	34.3	1.51
		39.20

These experiments were made at Chestnut Hill Reservoir,* Boston.

Since evaporation depends largely upon the temperature of the water, there would be less evaporation where the water is cooler and more where it is warmer than at Chestnut Hill Reservoir.

The above table and other evaporation experiments indicate that each nine degrees, Fahrenheit, of change in water temperature corresponds to about one inch per month of change in the amount of evaporation. A smaller evaporation than that given by the above table was used in determining the yield of water surfaces on the Sebago Lake drainage area.

In computing the yield of water surfaces in gallons per day by the method indicated, allowance was made in practically all cases for the reduction in the area of water surfaces as the reservoirs were drawn down.

* The rate of evaporation has been measured in Maine by the United States Geological Survey in coöperation with private parties, at four places, during a part or the whole of the period from July 1, 1905, to November 7, 1908, and the results are given in Water Supply Paper No. 279, entitled, "Water Resources of the Penobscot River Basin, Maine." The annual evaporation, as deduced from these measurements, is substantially 26 inches.

YIELD FROM LAND SURFACES.

In some cases, as, for instance, the drainage areas of the Manhan River and Tillotson Brook, and the drainage areas in the Catskill Mountains, the water surfaces were practically negligible, so that the flow from the whole drainage area is practically identical with the flow from the land surfaces. In other cases, the yield of the water surfaces was computed and subtracted from the total yield for each month, the remainder being the yield from land surfaces, and this divided by the number of square miles of land surface gave as a quotient the yield per square mile of land surface. The area of the land surface increased slightly as reservoirs were drawn down, but no account has been taken of this increase, the area of land surface used for a divisor being that corresponding to high water in the reservoirs.

SWAMPS.

As already indicated, the yield of swamps is less than that from land surfaces, and probably more than that from water surfaces. No actual measurements of the yields from such areas have been made, but a study of the subject in some detail indicated that a correction might be made for the effect of swamps by classing 40 per cent. of the area of an undrained swamp with the water surfaces and 60 per cent. with the land surfaces. In the case of swamps which have been carefully drained to improve the quality of the water supplied to a reservoir, the percentages assumed are, respectively, 30 and 70.

COMPILATION OF RETURNS.

After the various returns had been received, they were put in form for presentation to the Association by rewriting to make them more concise and uniform, by adding additional information to the descriptive matter, and by including the results of certain computations required to make the tables of yield more complete.

The amended descriptions and tables of yield are given in Appendix No. 1. The tables as presented therein are in somewhat different form from those received by the committee in answer to its inquiries for information. Certain columns in the original tables which have little practical value for purposes of record have

been omitted, to make room for other columns containing computed results which are more instructive.

A preliminary examination of the different records made it very evident that there were large differences in the yield per square mile of different drainage areas, even after corrections had been made for variation in the extent of the water surfaces. In order that these differences might be shown as clearly as practicable, a table was prepared for each drainage area, made up in the following manner: A search was made through the records to ascertain for each drainage area the yield per square mile of land surface in the driest month; then in the driest two consecutive months, and so on, until a table was completed which gave the average yield per square mile of each drainage area for all periods from one month to the full number covered by the record.

In making this table, no account was made of the different lengths of the different months of the year, as that would have involved much computation and seemed to be an unnecessary refinement; that is, the yield in gallons per day per square mile for a 30- and a 31-day month was averaged directly, instead of giving greater weight to the yield during the longer month.

The following — a part of the Wachusett table — is given as a specimen:

TABLE 3.

WACHUSETT DRAINAGE AREA.

Driest Consecutive Months on Basis of Yield from Land Surface.

Number of Consecutive Months.	Driest Consecutive Months.	Average Yield in Gallons per Day per Square Mile.
1	Oct., 1910	158 000
2	Sept.–Oct., 1910	190 000
3	July–Sept., 1913	205 000
4	July–Oct., 1910	240 000
5	July–Nov., 1910	251 000
6	July–Dec., 1910	274 000
7	July, 1908–Jan., 1909	334 000
8	June, 1908–Jan., 1909	376 000
9	June, 1910–Feb., 1911	442 000
10	May, 1910–Feb., 1911	477 000
11	Apr., 1910–Feb., 1911	536 000
12	Sept., 1910–Aug., 1911	582 000
13	Sept., 1910–Sept., 1911	557 000
14	Aug., 1910–Sept., 1911	538 000
15	July, 1910–Sept., 1911	521 000
16	July, 1910–Oct., 1911	532 000
17	June, 1910–Oct., 1911	556 000
18	May, 1910–Oct., 1911	570 000

Having completed such tables, the results were plotted on diagrams so that the differences might be shown graphically. These diagrams are reproduced herewith. (See Plates IX, X, and XI.)

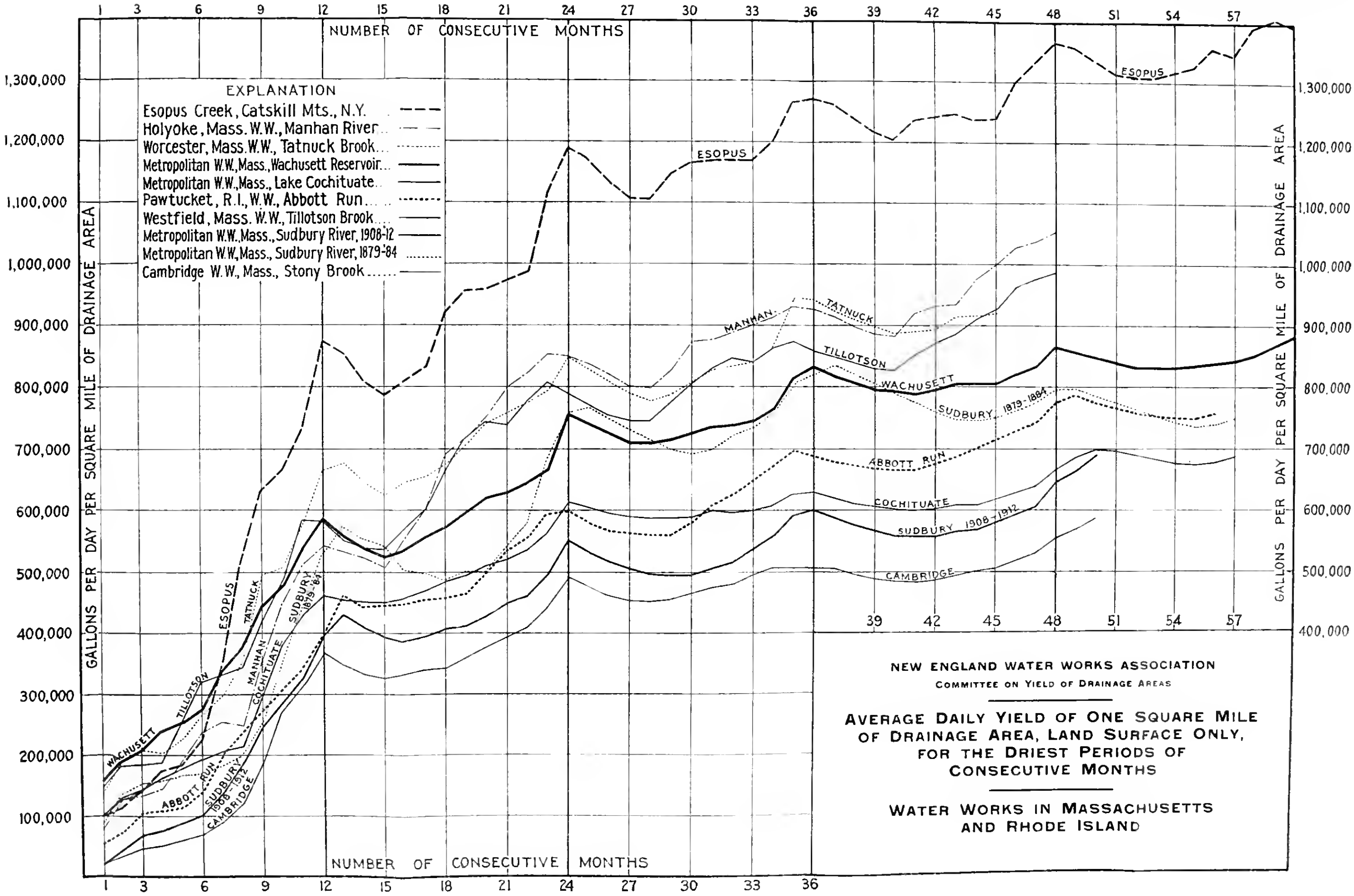
The diagrams were constructed in the following manner: At the bottom is shown the number of consecutive months, from 1 to 60. The vertical scale shown on the left-hand side represents the yield in gallons per day per square mile of drainage area. The lines on the diagram, each representing a drainage area, were plotted from the tables already described, and they show the mean yield of the drainage area for the number of consecutive months of minimum yield shown at the bottom of the diagram. For instance, if it were desired to know the yield of the various drainage areas on Plate IX for the driest six consecutive months during the dry period under consideration, one would look first for the six months period at the bottom of the diagram, and then could read directly from the vertical scale that the yields were as follows:

Drainage Area.	Average Yield per Square Mile. Gallons per Day.
Cambridge	68 000
Sudbury, 1908–1912	100 000
Abbott Run	140 000
Sudbury, 1879–1884	169 000
Cochituate	192 000
Esopus Creek	225 000
Manhan River	237 000
Tatnuck Brook	265 000
Wachusett	274 000
Tillotson Brook	319 000

For a period of thirty-two months, the corresponding figures for the same drainage areas are as follows:

Drainage Area.	Average Yield per Square Mile. Gallons per Day.
Cambridge	478 000
Sudbury, 1908–1912	511 000
Cochituate	595 000
Abbott Run	624 000
Sudbury, 1879–1884	721 000
Wachusett	737 000
Tatnuck Brook	832 000
Tillotson Brook	846 000
Manhan River	898 000
Esopus Creek	1 165 000

These diagrams, and the above figures taken from them, show that there is a very radical difference in the yield of different


NUMBER OF CONSECUTIVE MONTHS
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Holyoke, Mass. W.W., Manhan River
Worcester, Mass. W.W., Tatnuck Brook
Metropolitan W.W., Mass., Wachusett Reservoir
Metropolitan W.W., Mass., Lake Cochituate
Pawtucket, R.I., W.W., Abbott Run
Westfield, Mass. W.W., Tillotson Brook
Metropolitan W.W., Mass., Sudbury River, 1908-12
Metropolitan W.W., Mass., Sudbury River, 1879-84
Cambridge W.W., Mass., Stony Brook
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
ESOPUS
MANHAN
TATNUCK
TILLOTSON
WACHUSETT
SUDBURY 1879-1884
ABBOTT RUN
COCHITUATE
SUDBURY 1908-1912
CAMBRIDGE
NEW ENGLAND WATER WORKS ASSOCIATION
COMMITTEE ON YIELD OF DRAINAGE AREAS
AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, LAND SURFACE ONLY, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS
WATER WORKS IN MASSACHUSETTS AND RHODE ISLAND

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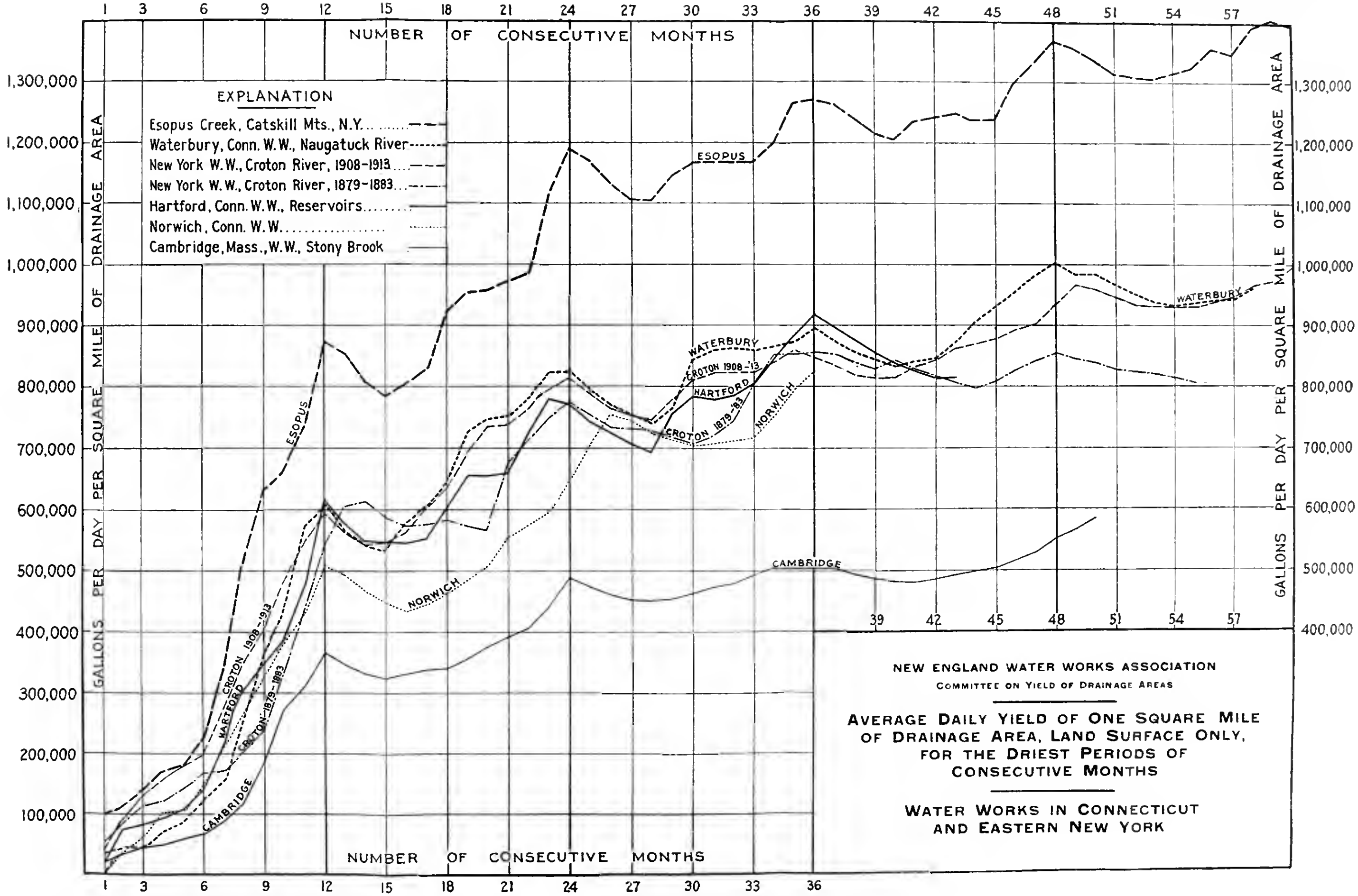
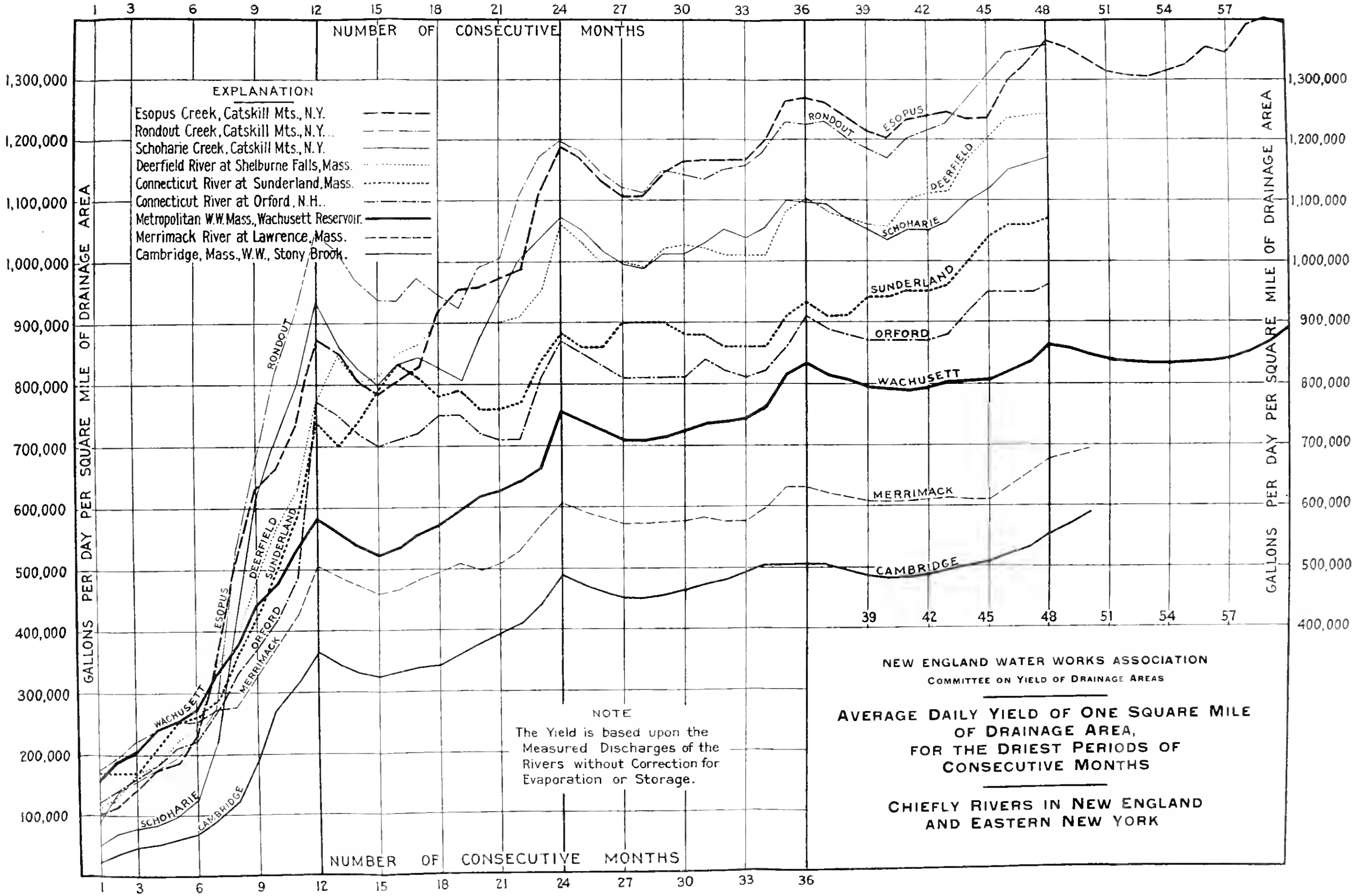

NUMBER OF CONSECUTIVE MONTHS
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Waterbury, Conn. W.W., Naugatuck River
New York W.W., Croton River, 1908-1913
New York W.W., Croton River, 1879-1883
Hartford, Conn. W.W., Reservoirs
Norwich, Conn. W.W.
Cambridge, Mass., W.W., Stony Brook
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
ESOPUS
WATERBURY
CROTON 1908-'13
HARTFORD
CROTON 1879-'83
NORWICH
CAMBRIDGE
NEW ENGLAND WATER WORKS ASSOCIATION
COMMITTEE ON YIELD OF DRAINAGE AREAS
AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, LAND SURFACE ONLY, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS
WATER WORKS IN CONNECTICUT AND EASTERN NEW YORK


NUMBER OF CONSECUTIVE MONTHS
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Rondout Creek, Catskill Mts., N.Y.
Schoharie Creek, Catskill Mts., N.Y.
Deerfield River at Shelburne Falls, Mass.
Connecticut River at Sunderland, Mass.
Connecticut River at Orford, N.H.
Metropolitan W.W. Mass., Wachusett Reservoir.
Merrimack River at Lawrence, Mass.
Cambridge, Mass., W.W., Stony Brook.
ESOPUS
RONDOUT
DEERFIELD
SCHOHARIE
SUNDERLAND
ORFORD
WACHUSETT
MERRIMACK
CAMBRIDGE
NOTE
The Yield is based upon the Measured Discharges of the Rivers without Correction for Evaporation or Storage.
NEW ENGLAND WATER WORKS ASSOCIATION
COMMITTEE ON YIELD OF DRAINAGE AREAS
AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS
CHIEFLY RIVERS IN NEW ENGLAND AND EASTERN NEW YORK

drainage areas, and that the results obtained upon one cannot be applied indiscriminately to another in order to obtain the probable yield of such drainage area. Such a conclusion makes it necessary to consider how the differences in the yield of different drainage areas can be accounted for, and to ascertain the general laws, as far as they can be ascertained, which affect the application of the yield of one drainage area to another.

Plate IX is intended to show the yield of water supply drainage areas in Massachusetts and Rhode Island, but there is included also, for the purpose of comparison, the yield of Esopus Creek of the New York water supply.

Plate X is intended to show the yield of water supply drainage areas in Connecticut and of the Croton supply in eastern New York, but there is added to the plate the yield of the Stony Brook drainage area of the Cambridge Water Works and the yield of Esopus Creek, to represent the lowest and highest yields recorded during the period under consideration.

Plate XI is mainly for the purpose of showing the yield of rivers, not corrected either for the effect of storage or for the effect of water surfaces; that is to say, the figures given are the actual measurements of the streams without correction. The yield of the Wachusett and Cambridge drainage areas are presented on this plate for the purpose of comparison. It is to be noted that in the majority of cases the discharge of the rivers is based on a rating curve and measurements of the height of the water in the river once or twice a day. There is likely to be a considerable error when this method is used, especially when the streams are covered with ice, and the quantity discharged is likely to be too large rather than too small; moreover, if there are water powers on a stream, causing a variable flow, heights taken at fixed times once or twice a day may not represent the average height during the twenty-four hours.

Especial care is taken to obtain an accurate measurement of the discharge of the Merrimack River,* and at Esopus Creek a special weir has been in use most of the time to measure the discharge.

* The Lawrence records of the Merrimack River discharge are those used in this report. These records have been compared with the Lowell records for the years 1908–1913, and the difference between the discharge per square mile at Lawrence and Lowell by different methods of measurement is not more than 5 per cent.

RELATION BETWEEN PRECIPITATION AND YIELD.

The most important factor affecting the yield or run-off from a drainage area is the amount of precipitation upon it, and this in turn is governed to a very considerable extent by the elevation of the drainage area.

The best proof of the marked effect of differences in the amount of annual precipitation on the per cent. of the precipitation which runs off is furnished by records from the same drainage area under similar conditions in years of high and low precipitation.

The following table shows the results obtained by comparing the years of high and low precipitation on several drainage areas where there are records for a long series of years. In the cases of the Sudbury and Croton drainage areas, where the series of measurements covers a very long period, the highest six years' and the lowest six years' precipitation were used, and in the cases of the Wachusett records and those of the Perkiomen, Neshaminy, and Tohickon creeks, near Philadelphia, where the records cover a shorter period, the highest and lowest four years' precipitation were used.

TABLE 4.

COMPARISON OF RUN-OFF IN YEARS OF HIGH AND LOW PRECIPITATION.

Drainage Area.	Period.	Average Precipitation. Inches.	Average Run-off. Inches.	Per Cent. of Run-off.
Wachusett	Highest 4 yrs.	54.48	29.27	53.7
	Lowest 4 yrs.	38.65	17.08	44.2
	Difference	15.83	12.19	77.0
Sudbury	Highest 6 yrs.	55.17	29.10	52.7
	Lowest 6 yrs.	36.39	13.53	37.2
	Difference	18.78	15.57	82.9
Croton	Highest 6 yrs.	59.42	31.93	53.7
	Lowest 6 yrs.	40.59	18.50	45.6
	Difference	18.83	13.43	71.3
Average of Perkiomen, Neshaminy, and Tohickon	Highest 4 yrs.	55.06	29.16	53.0
	Lowest 4 yrs.	42.35	19.47	46.0
	Difference	12.71	9.69	76.2
All sources	Highest 20 yrs.	56.29	30.00	53.3
	Lowest 20 yrs.	39.29	16.92	43.1
	Difference	17.00	13.08	77.0

The above table shows clearly the very much larger per cent. of run-off when the precipitation is large than when it is small. An analysis of the figures at the bottom of the table, giving the results for all sources, shows that while the per cent. of run-off corresponding to an annual precipitation of 39.29 in. is 43.1, the per cent. of run-off from the additional precipitation, that is, from the difference between the precipitation in the highest and lowest years, is 77.0 per cent. This result is obtained by taking the difference between the run-off for the high and low periods, amounting to 13.08 in., and dividing it by the difference in the precipitation for these periods, amounting to 17.00 in.

It is the very high percentage of run-off from the difference in precipitation which accounts to a considerable extent for the difference in the run-off per square mile of different drainage areas.

While the amount of precipitation is generally the most important factor affecting the amount of run-off from a drainage area, there are other important factors, such as the relative amount of precipitation in different portions of the year, the character of the soil, the temperature of the air, the steepness of the slopes, and the extent to which the areas are forested. The effect of differing amounts of precipitation upon the run-off may be approximated from the comparisons above given, which show that when the annual precipitation varies from 39.29 in. to 56.29 in., 77.0 per cent. of the difference in precipitation is represented by the run-off. This same percentage would not hold with the smaller precipitation during the years under consideration in this report, but it will not be far in error to assume arbitrarily that when the precipitation varies between 35 and 40 inches and between 40 and 45 inches, 65 and 70 per cent., respectively, of the variation will be represented in the run-off, instead of the 77.0 per cent. applicable to the larger precipitation.

It is difficult to differentiate the effect of the other factors, except that relating to the distribution of the precipitation in different portions of the year.

The following table has been prepared to show to what extent the differences in the run-off from different drainage areas during the recent period of dry years can be accounted for by the differences in precipitation, using the computations based on the assumptions

above stated and the further assumption that with 40 in. of annual precipitation the normal flow from an ordinary drainage area during the four years under consideration, from 1908 to 1911, inclusive, would have been 870 000 gal. per day per square mile of land surface.

TABLE 5.

RELATION BETWEEN PRECIPITATION AND YIELD AS COMPUTED AND MEASURED.

Drainage Area.	Average Annual Precipitation during Dry Years. Inches.	Yield of Land Surface in Gal. per Day per Sq. Mile.		
		Computed as Above Described.	Measured.	Difference of Measured from Computed Quantity.
Esopus Creek	46.89	1 099 000	1 415 000	+316 000
Rondout Creek	45.94	1 068 000	1 355 000	+287 000
Croton River	45.89	1 066 000	987 000	—79 000
Holyoke, Manhan River	45.04	1 038 000	1 053 000	+15 000
Westfield, Tillotson Brook	44.63	1 024 000	974 000	—50 000
Waterbury, West Branch of Naugatuck River	43.07	972 000	999 000	+27 000
Worcester, Tatnuck Brook	40.96*	902 000	983 000*	+81 000
Standard Assumed	**40.00**	**870 000**		
Wachusett Reservoir	39.73	862 000	895 000	+33 000
Pawtucket, Abbott Run	39.23	846 000	809 000	—37 000
Schoharie Creek	38.41	821 000	1 170 000	+349 000
Sudbury River	37.98	808 000	676 000	—132 000
Cambridge, Stony Brook	36.67	767 000	565 000	—202 000

By referring to the third column of the table, it will be noted that the yield in gallons per day per square mile of land surface should vary on account of the difference in the amount of annual precipitation from 767 000 to 1 099 000 gal. per day per square mile. The measured yields vary much more than this, and the differences between the computed and measured yields, as given in the last column of the table, result from other causes than the differences in the amount of precipitation as recorded. In a majority of cases the computed and measured yields show an approximate

* This precipitation is based on the average of records at Tatnuck Brook, Lynde Brook, Kettle Brook, and Jefferson, which are, respectively, 1.5, 4.5, 2.5, and 4.0 miles from the center of the Tatnuck Brook drainage area. The yield for the first five months of 1908, as recorded in the Worcester records, appears to be too large, and a yield for these months deduced from the rainfall at Tatnuck Brook, using the percentage of run-off determined for the adjacent Wachusett drainage area, has been used instead.

agreement, but the measured yields of the Catskill Mountain sources are far in excess of those computed, while the reverse is true of the Stony Brook and Sudbury River yields.

DISTRIBUTION OF ANNUAL PRECIPITATION AFFECTS THE AMOUNT OF RUN-OFF.

The distribution of the precipitation throughout the year is an important matter when one is attempting to deduce the run-off from it, because a large per cent. of the precipitation during the colder portions of the year runs off, while during the warmer portions the reverse is true. This is shown by the following table, based upon the records for the years 1908 to 1911 inclusive.

TABLE 6.

PER CENT. OF PRECIPITATION RUNNING OFF IN DIFFERENT PORTIONS OF THE YEAR.

Drainage Area.	Per Cent. Running Off.		
	December to April.	May, June, and November.	July to October.
Schoharie Creek	107.3	50.4	15.5
Esopus Creek	95.2	60.7	18.5
Rondout Creek	93.6	58.3	19.3
Worcester, Tatnuck Brook	79.2	51.5	14.8
Waterbury, West Branch of Naugatuck River	73.5	43.5	15.6
Wachusett Reservoir	70.2	48.3	15.5
Westfield, Tillotson Brook	69.1	46.7	17.1
Holyoke, Manhan River	68.4	52.8	18.8
Pawtucket, Abbott Run	66.6	36.5	13.4
Croton River	65.0	42.6	15.9
Sudbury River	58.8	31.9	7.7
Cambridge, Stony Brook	52.2	27.3	7.2
Averages, omitting first three and last two	70.3	46.0	15.9

The table shows the per cent. of the precipitation which runs off in different groups of months. The first group covers the period from December to April, inclusive, representing the colder months from December to March, inclusive, and the month of April when

much of the water precipitated in the previous months in the form of snow flows off in the streams.

The second group includes the months of May, June, and November, when the per cent. running off is fairly large, and the third group the months from July to October, inclusive, when the per cent. running off is low.

The table was prepared primarily to show the much larger per cent. running off in the cold months than in the dry portions of the year, and to call attention to the fact that when the precipitation is relatively low in the colder months the yield from a drainage area with a given annual precipitation will be less than with the same annual precipitation when a larger part falls in the cold months.

Before discussing the table along these lines, it is well to note the very high per cent. running off during the colder months from the drainage areas of the three creeks in the Catskill Mountains, while the per cent. running off from these same drainage areas from July to October differs but little from that of most of the other sources. It is, of course, impossible that the run-off should exceed the precipitation upon a drainage area, unless some of the precipitation of previous months is included in the run-off. This frequently happens when one is dealing with the run-off of individual months in the winter and spring, as the snow falling in one month melts and runs off in the succeeding months, but when a group of months is taken, covering practically the whole winter and a sufficient time in the early spring to insure the melting of all of the snow, the run-off for the period will always be less than the precipitation because even in the winter there is a loss of water by evaporation.

The fact that the run-off from Schoharie Creek during the winter months exceeds the recorded precipitation, and that the run-off from Esopus and Rondout creeks during the same months is a very large proportion of the precipitation, represents an unusual condition, and it has been suggested that it may be accounted for in several ways; first, that snow frequently falls upon these mountainous drainage areas in November which does not melt and run off until a subsequent month; second, that it is impracticable to obtain the precipitation upon the higher portions of the

mountains because these places are entirely inaccessible during the winter; and third, that the difficulty of measuring the streams during the winter months in such an extremely cold climate, when much ice forms, may have resulted in recording discharges greater than the actual discharges of the streams.

The first of these suggestions does not seem to have very much weight, because during the period covered by the table there was no noticeable deficiency in the November run-off, as there would have been had much of the November precipitation been in the form of snow which remained on the ground to the end of the month, and the amount of water carried over from November to December in the form of snow would have been largely offset by the greater amount of water stored in the interstices of the ground at the end of April. It is known that there is more water in the ground at the end of April than at the beginning of December, because the streams at times when they are not affected by rains are much higher at the end than at the beginning of this winter period.

The second suggestion that the precipitation upon the tops of the mountains is greater than is indicated by the rainfall records has weight.* As has already been stated, the rain gages are maintained at as high a level as observers can be found, but none of them are located on or near the tops of the highest mountains, and the precipitation is probably much higher upon these mountains than upon the parts of the drainage area represented by the rain gages. It is even supposable that there may be a considerable condensation of moisture from the atmosphere at these high points, especially in winter, which is not represented by any precipitation which can be measured. Even at the higher stations where observers are available it may be impracticable to obtain thoroughly trustworthy records, on account of the high winds in these elevated places and the difficulty of obtaining suitable gage keepers. Winter records of precipitation are more likely to be too low than too high.

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* A rain gage was maintained at the top of Mount Washington from 1872 to 1886, the average annual rainfall recorded in this period being 83.53 in., while that at Lake Cochituate for the same period was 42.92 in. A comparison of the annual rainfall from 1876 to 1886, inclusive, on Mount Washington with the same period at Lake Cochituate and on the Sudbury River watershed shows the following results: Mount Washington, 90.13; Lake Cochituate, 42.59; Sudbury River, 44.02.

The third suggestion that the recorded discharge may be too high during the ice period may account to a large extent for the extremely high per cent. running off during the cold months. It is a matter of extreme difficulty to obtain a trustworthy measurement of streams when much ice is forming, not only as a covering over the surface of the streams in places, but as slush and anchor ice.

In addition to these causes for the high per cent. of precipitation recorded as run-off in the winter months, it is probable that the very low temperatures upon these drainage areas greatly reduce the evaporation during these months.

On the whole it seems best, in reaching any general conclusions as to the per cent. running off in different portions of the year, to omit the records of the three Catskill Mountain creeks and of the Sudbury River and Stony Brook drainage areas, which give abnormally high and low results. With these omissions, the average run-off, as shown in the last line of the table, is, during the winter period, 70.3 per cent.; in the months of May, June, and November, 46.0 per cent.; and in the period from July to October, inclusive, 15.9 per cent. Hence, during the years under consideration, an inch of precipitation in the cold months caused a run-off more than four times as great as an inch of precipitation during the period from July to October.

Special attention is called to the per cent. of precipitation running off from the Catskill Mountain drainage areas during the dry period from July to October, inclusive. The percentages as given in the last column of Table No. 6 are, respectively, 15.5, 18.5, and 19.3, averaging 17.8. This is but little larger than the 15.9 per cent. which runs off from ordinary drainage areas, a result which is surprising in view of the steep and somewhat impervious character of these mountain areas and the larger precipitation upon them.

Having shown by the foregoing table and statements that the per cent. running off is so much greater in some portions of the year than in others, it is now important to place on record the distribution of the precipitation upon the drainage areas under consideration for the different parts of the year, and this is done in the following table.

TABLE 7.

DISTRIBUTION OF PRECIPITATION IN DIFFERENT PORTIONS OF YEAR, FROM RECORDS OF 1908–1911, INCLUSIVE.

Drainage Area.	Per Cent of Total Precipitation. December to April.	May, June, and November.	July to October.
Schoharie Creek	42.1	28.0	29.9
Esopus Creek	44.5	23.8	31.7
Rondout Creek	45.6	22.9	31.5
Worcester, Tatnuck Brook	45.7	19.9	34.4
Waterbury, West Branch of Naugatuck River	47.1	20.7	32.2
Wachusett Reservoir	45.4	21.4	33.2
Westfield, Tillotson Brook	42.7	21.5	35.8
Holyoke, Manhan River	45.1	22.3	32.6
Pawtucket, Abbott Run	46.1	23.5	30.4
Croton River	47.1	22.4	30.5
Sudbury River	47.4	22.5	30.1
Cambridge, Stony Brook	45.9	22.2	31.9
Averages	45.4	22.6	32.0

It will be seen by reference to the table that upon all of the drainage areas under consideration the per cent. of precipitation in the different portions of the year is reasonably uniform. This indicates that there is a large territory to which the records of run-off are not made inapplicable by a dissimilar distribution of precipitation. This territory includes practically all drainage areas in Massachusetts, Rhode Island, and Connecticut, with the possible exception of a part of western Massachusetts.

In northern Vermont, however, the distribution of precipitation is very different. As an illustration, the average precipitation for twenty-five years at Lunenberg, Chelsea, Stafford, Woodstock, and Northfield, was 36.36 in., of which 36.9 per cent. fell in the period from December to April; 26.7 per cent. in May, June, and November; and 36.4 per cent. in the period from July to October. With such a distribution of precipitation, the run-off for the year would be less than when the distribution is as shown by the foregoing table.*

* The distribution of precipitation throughout the year is very fully treated in a paper recently presented to the Association by Mr. X. H. Goodnough, entitled, "Rainfall in New England."

By combining the final results given in Tables Nos. 6 and 7, it was found that during the four years under consideration 67.3 per cent. of the whole run-off occurred in the months from December to April inclusive; 21.9 per cent. in the months of May, June, and November; and 10.8 per cent. in the months from July to October inclusive.

COMPARISON OF RECENT AND FORMER DRY PERIODS.

The water-works engineer, as a rule, bases his estimates of the capacity of a given source of water supply upon the records of the driest period known to him, if such period is not too remote, and it is, therefore, of especial interest to know whether the recent dry period furnishes a new basis for estimating the capacity of water supplies.

The researches of the committee warrant the general statement that over a large part, if not the whole, of New England the recent dry period does furnish a new basis, as it is the driest period known since the gaging of streams in this section of the country was begun. Precipitation records indicate that still drier periods occurred prior to the year 1850, but none since that date. Upon the Croton watershed in New York, only a short distance west of the westerly limits of New England, the recent dry period is not quite as dry as the period from 1879–1883.

There is some danger that such a general statement may be misleading. For instance, a community taking a supply from a running stream or one having upon it only a very small reservoir, measures a drought by the quantity of water running in the stream in the driest day, week, or month, and the driest time for short periods may not have occurred in the two dry periods under consideration. The statement is true of periods of six or more consecutive months.

The superintendent of a water works who has a reservoir of moderate size which will surely fill and overflow each spring is concerned only with the amount of water flowing in the driest six to ten months of a single dry year, while one who has control of a water system like that of New York, the Metropolitan Water District, Worcester, and Salem, having reservoirs very

large in proportion to the drainage area feeding them, knows that the winter and spring flow is more important for his works than that of the drier portions of the year. Such supplies are depleted to a much greater extent by a succession of dry years than by one year of extreme drought.

The recent dry period has been extreme both in regard to the low flow during six months or more of a single year and during a long series of consecutive years. The drought in western New England and New York ended with phenomenally heavy rains in the autumn of 1911, but in eastern Massachusetts there was no large increase in the amount of run-off to the end of 1913, and to the present time in 1914 the discharge of the streams is but little above the average.

The only recorded gagings known to the committee, which covered the dry period of 1879 to 1883 and the recent dry period from 1908 to 1912, are those of the Cochituate, Sudbury, and Merrimack River drainage areas in New England and the Croton drainage area in New York. A comparison of the recorded yields of these drainage areas for the two periods is given in the tables which follow. The first table is a comparison of the average yield in million gallons per day per square mile of drainage area for different consecutive dry periods, which are selected with reference to their being the critical periods from the water supply standpoint. The second table shows the relative safe capacity of the sources with various assumed amounts of storage per square mile, and shows more accurately than the first table the relative dryness of the two periods from the water-works point of view.

On both the Sudbury and Croton drainage areas new reservoirs have been constructed and filled between these periods, so that it has been necessary to make corrections for evaporation and to base the tables upon the yield per square mile of land surface. On the Cochituate and Merrimack River drainage areas there have been no important changes, and the records have been used without such corrections.

The comparisons made in Table 8 show plainly that the recent dry period has been drier on the Cochituate, Sudbury, and Merrimack drainage areas than that of 1879–1883, while the reverse is true on the Croton drainage area. For periods varying

TABLE 8.

COMPARISON OF THE DRY PERIODS 1879–1883 and 1908–1912, BASED ON MEAN RUN-OFF DURING PERIODS OF DIFFERENT LENGTHS.

(All quantities in million gallons per day per square mile.)

Length of Dry Period. Months.	Cochituate. Average Run-off.		Cochituate. Later Period LESS than Former. Per Cent.	Sudbury. Average Run-off.		Sudbury. Later* Period LESS than Former. Per Cent.	Merrimack. Average Run-off.		Merrimack. Later Period LESS than Former. Per Cent.	Croton. Average Run-off.		Croton. Later Period MORE than Former. Per Cent.
	1879–83.	1908–12.		1879–83.	1908–12.		1879–83.	1908–11.		1879–83.	1908–12.	
6	.137	.102	26	.169	.100	41	.317	.252	21	.168	.200	19
7	.182	.123	32	.182	.138	24	.370	.274	26	.173	.278	61
8	.200	.159	21	.200	.185	8	.380	.279	27	.201	.349	74
9	.252	.237	6	.251	.244	3	.399	.325	19	.239	.404	69
18	.412	.387	6	.486	.405	17	.532	.493	7	.581	.634	9
19	.417	.403	3	.499	.410	18	.571	.509	11	.572	.692	21
20	.440	.420	5	.500	.426	15	.618	.499	19	.567	.734	29
30	.532	.508	5	.691	.493	29	.731	.576	21	.707	.811	15
31	.538	.516	4	.698	.505	28	.730	.581	20	.720	.822	14
32	.544	.526	3	.721	.511	29	.770	.577	25	.742	.823	11
42	.583	.527	10	.758	.555	27	.775	.610	21	.817	.842	3
43	.576	.534	7	.748	.563	25	.767	.612	20	.807	.863	7
44	.574	.540	6	.746	.566	24	.767	.610	20	.799	.870	9

* The differences given in this column would probably have been much smaller if it had been feasible to obtain an accurate measurement of the run-off in 1908–1912.

from nine to forty-four months the mean run-off has been from 3 to 10 per cent. less on the Cochituate drainage area, 3 to 29 per cent. less on the Sudbury drainage area, and 7 to 25 per cent. less on the Merrimack drainage area in the recent than in the former dry period.

In the years 1908–1912, there was practically no extreme drought upon the Croton drainage area for periods of from six to nine months, but for periods of from eighteen to forty-four months the yield, although very low, was from 3 to 29 per cent. greater than in the former dry period.

Such comparisons as those just given are somewhat unsatisfactory because the critical periods from a water-supply standpoint do not have exactly the same length in different years, and a better comparison can be made by computing the safe yields of these drainage areas during the two dry periods, assuming various fixed amounts of storage capacity per square mile of drainage area. For example, let it be assumed that the available storage capacity upon the Cochituate drainage area is 83 500 000 gal. per square mile of drainage area, and assume further that this amount of storage does not change the existing proportion of land and water surfaces. Under these assumed conditions, the safe capacity of the drainage area per square mile would have

TABLE 9.

COMPARISON OF THE DRY PERIODS 1879–1883 AND 1908–1912, BASED ON SAFE CAPACITY OF DRAINAGE AREAS WITH VARYING AMOUNTS OF STORAGE.

(All storage and safe capacities in this table are per square mile of drainage area.)

Cochituate (Whole Drainage Area).				Sudbury (Land Surface).			
Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later Period LESS than Former. Per Cent.	Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later* Period LESS than Former. Per Cent.
	1879–83.	1908–12.			1879–83.	1908–12.	
18.2	228 000	200 000	12.3	18.4	208 000	200 000	3.8
37.9	344 000	300 000	12.8	36.8	353 000	300 000	15.0
59.1	441 000	400 000	9.3	56.4	430 000	400 000	7.0
83.5	541 000	500 000	7.6	77.9	518 000	500 000	3.5
175.2	724 000	700 000	3.3	189.0	809 000	700 000	13.5
547.0	911 000	900 000	1.2	313.5	925 000	800 000	13.5

* The differences given in this column would probably have been much smaller if it had been feasible to obtain an accurate measurement of the run-off in 1908–1912.

Merrimack (Whole Drainage Area).				Croton (Land Surface).			
Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day. 1879–83.	Safe Daily Capacity. Gallons per Day. 1908–12.	Later Period LESS than Former. Per Cent.	Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day. 1879–83.	Safe Daily Capacity. Gallons per Day. 1908–12.	Later Period MORE than Former. Per Cent.
0.9	200 000	200 000	0.0	6.6	177 000	200 000	13.0
8.8	337 000	300 000	11.0	18.4	259 000	300 000	15.8
29.4	477 000	400 000	16.1	36.8	345 000	400 000	15.9
53.7	595 000	500 000	16.0	55.2	426 000	500 000	17.4
123.2	757 000	700 000	7.5	92.0	572 000	700 000	22.4
260.0	961 000	800 000	16.8	117.0	662 000	800 000	20.8
				164.0	836 000	900 000	7.7

been, in the period 1908–1912, 500 000 gal. per day; and in the period 1879–1883, 541 000 gal. per day. With this amount of storage, therefore, the safe capacity in the later period would have been 7.6 per cent. less than in the earlier period.

The table preceding gives the safe capacity of the four drainage areas under consideration, with differing amounts of storage per square mile of drainage area.

DRY PERIODS PRIOR TO 1850.

As the statement has been made that "precipitation records indicate that still drier periods occurred prior to the year 1850," it may be of interest to present a comparison between the yields during some of these periods, as deduced from the precipitation records, and the yield of the Wachusett drainage area during the recent dry period.

The following reliable long-continued precipitation records are available:

New Bedford, Mass. .... Record begins in 1814
Boston, Mass. .... Record begins in 1818
Amherst, Mass. .... Record begins in 1836
Lowell, Mass. .... Record begins in 1825
Waltham, Mass. .... Record begins in 1826
Providence, R. I. .... Record begins in 1832

The period beginning in June, 1837, and extending to the end of October, 1838, was probably from 7 to 15 per cent. drier than

the most intense part of the recent dry period on the Wachusett drainage area — that is, the period from June, 1910, to October, 1911, inclusive. The estimated deficiency during the earlier period is as follows:

New Bedford, Mass.	9 per cent.
Boston, Mass.	3 per cent.
Amherst, Mass.	7 per cent.
Lowell, Mass.	14 per cent.
Waltham, Mass.	3 per cent.
Providence, R. I.	15 per cent.
Average	8.5 per cent.

If, in making the comparison, a longer period had been used, covering the years 1837–1840 and the years 1908–1911, the results would not have been materially changed.

A far drier period even than 1837–1838 is indicated by the precipitation records at Boston for 1821–1822. Comparing the period from June, 1821, to October, 1822, with the period from June, 1910, to October, 1911, on the Wachusett drainage area, it appears that the probable yield in the earlier period would have been 30 per cent. less than in the later one.

The only other records available for this period are those at New Bedford, a study of which does not indicate that the yield at that time was lower than on the Wachusett drainage area in 1910–1911. Other contemporary observations of conditions in 1821–1822 indicate that the flow of streams in eastern New England was very low.

The records of precipitation at Boston and Providence in the years 1832–1833 indicate that the yield of drainage areas in the period from June, 1832, to October, 1833, inclusive, would have been from 7 to 17 per cent. less than from the Wachusett drainage area during the corresponding months in 1910–1911. The records of the precipitation at Lowell and New Bedford in these years indicate a less severe drought at those places than at Boston and Providence.

Precipitation records for 1845–1846 also indicate a very dry period, the precipitation in the later year probably being lower than in any subsequent year up to the present time. During the period from June, 1845, to October, 1846, the yield of the drainage

areas in eastern New England was probably less than that of the Wachusett drainage area in the corresponding months in 1910, 1911, by an amount not exceeding 10 per cent.

Similarly, the observations at Amherst and Providence from June, 1848, to October, 1849, indicate a yield from 2 to 10 per cent. less than that of the Wachusett drainage area in the corresponding period in 1910–1911. The precipitation records in other parts of New England for these years indicate that the drought was quite general throughout a large part of New England.

TABLES AND DIAGRAMS TO FACILITATE COMPUTATION OF SAFE CAPACITY OF SOURCES.

The thirteen tables, which are called "Capacity Tables," given subsequently, and the twelve diagrams which show graphically the results shown by twelve of the tables, are presented to facilitate the computation of the so-called "safe capacity" of sources of water supply. The tables should be used with judgment, and attention is called to a subsequent section entitled "**Caution,**" and to Appendix No. 2 (page 525) which explains the method used for their computation.

They are intended to show the storage capacity required to supply in the driest periods various quantities of water daily from one square mile of drainage area containing water surfaces varying from 0 to 15 per cent., and may be used when the storage capacity is known to determine the safe daily capacity of the sources of supply, or may be used equally well to deduce the required storage capacity when the daily quantity of water desired is known.

It needs but little explanation to show how the tables may be used. The first column gives the constant daily quantity of water to be drawn from the source, in gallons per square mile of drainage area, including water surfaces. The remaining columns show the quantity of storage required per square mile of drainage area in order to provide the constant daily quantity given in the first column, when there are water surfaces amounting to 0, 5, 10, and 15 per cent. of the total drainage area.

The quantity of storage required for other percentages of water

surface may easily be obtained by interpolation, or directly from the diagrams.

TABLE 10.

AVERAGE ELEVATIONS OF DRAINAGE AREAS.

Drainage Area.	Average Elevation above Sea Level. Feet.	Drainage Area. Sq. Miles.	Period Covered.
Cambridge, Stony Brook. . .	180	23.57	1908–1912
Pawtucket, Abbott Run. . . .	150	26.94	1908–1912
Metropolitan Water Works:			
Sudbury River.	300	75.20	1879–1884
Sudbury River.	300	75.20	1908–1912
Wachusett Reservoir. . . .	750	118.19	1908–1914
Worcester, Tatnuck Brook.	950	5.231	1908–1912
Holyoke, Manhan River. . .	950	13.00	1900, 1908–1911
Westfield, Tillotson Brook. .	990	5.84	1908–1911
Waterbury, West Branch of Naugatuck River.	890	18.00	1908–1912
Hartford Reservoirs.	460	11.92	1909–1912
New York Water Works:			
Croton River.	620	338.8	1879–1883
Croton River.	600	360.4	1908–1913
Esopus Creek.	1700	239.0	1908–1913

The characteristics of these drainage areas are fully described in Appendix No. 1, but a brief statement regarding them is inserted in this place.

Cambridge, Stony Brook. This drainage area probably gives the smallest yield of any of those from which records were received, but the low yield as given in the records and as reflected in the capacity table for this source is due in part to certain losses of water by leakage and by evaporation from swamps, which are not accounted for in the computations. In nearly all cases the capacity of a source based upon these records will be lower than the actual capacity of the source.

Pawtucket, Abbott Run. The results appear to be accurate.

Metropolitan Water Works, Sudbury River. The records of the dry period 1879–1883 are accurate, but they represent a period not quite as dry as the recent dry period. The records of 1908–1912 are probably not accurate, especially for periods of eight months or less, and the capacity of a source based upon these records will be as a rule too low.

Metropolitan Water Works, Wachusett Reservoir. These records are unusually accurate. They represent a drainage area having a large percentage of water surfaces and large storage capacity, and for this reason are not as applicable to drainage areas having a small percentage of water surfaces and small storage as are many of the other records.

Worcester, Tatnuck Brook. The records appear to be accurate except when the water is flowing over the spillway, at which time the results appear to be rather high. During the critical period upon which the greater part of the capacity table is based there was little or no water flowing over the spillway. In cases where there is a very large storage per square mile of drainage area, the results based on this capacity table may be somewhat too large. The drainage area is only about 5 square miles — so small that it is more difficult to obtain accurate results than from a larger drainage area.

Holyoke, Manhan River. The records appear to be accurate.

Westfield, Tillotson Brook. The records appear to be accurate. It is a disadvantage that the drainage area is only about six square miles.

Waterbury, Naugatuck River. The records appear to be accurate, but some of the water wasted is at times discharged through a blow-off, and the measurement at such times is only approximate. Upon the Croton drainage area, which is not far distant from Waterbury, the recent drought was not as severe as that of the years 1879–1883, and it is quite likely that the drought at Waterbury was not as severe as in most parts of New England.

Hartford Reservoirs. The accurate records begin in June, 1909, and consequently the records of the whole of the dry period which began in June, 1908, are not available. This does not affect the capacity table, except in the portions which relate to highly developed sources, and the safe capacity deduced from the table in such cases will probably be larger than if the records had been available from June 1, 1908.

New York Water Works, Croton River. These are standard records and are supposed to be trustworthy. Two capacity tables are furnished. That covering the years 1879–1883 represents a lower yield than that covering the period 1908–1913; consequently,

the latter table is of little value. The storage capacity and area of water surfaces increased greatly between the two periods.

New York Water Works, Esopus Creek. The records are accurate when there is no ice in the streams, and fairly good at such times. The drainage area is at a far greater elevation above the sea than most of the drainage areas, and consequently has a high precipitation and a run-off far in excess of ordinary drainage areas. It is also probable that the drought was not as severe here as in New England.

As a general rule, it is desirable in making computations of the capacity of sources to exclude the records based upon Stony Brook, Sudbury River 1908–1912, Croton River 1908–1913, and Esopus Creek; also in determining the safe capacity of drainage areas with very small water surfaces to give little weight to or to exclude the results obtained from drainage areas having large water surfaces.

CAUTION.

While the capacity tables have been computed on the basis of the records of the yield of different drainage areas during the recent period of extremely dry years, and are in general correct and the best basis for computing the yield of other drainage areas, they are not, when each table is considered as a whole, equally good, and different parts of the same table are not equally trustworthy.

The principal causes of inaccuracy, aside from those already noted in the comments upon the different drainage areas above given, are given below. The first two affect chiefly the larger figures in the tables and the last three the smaller figures; the intermediate figures are not affected in all cases. The causes of these inaccuracies are:

1. Basing the estimate of required storage for highly developed sources on records extending from 1908 to 1911 or 1912, instead of to 1914 or later.

2. Using some records which do not represent the driest period of years.

3. Basing computations on monthly instead of daily yield.

4. Deducing small yields of land surfaces from records of drainage areas having large reservoirs.

5. Assuming that the recent period of dry years includes the driest period of only a few months.

Besides the above causes of inaccuracy, which need to be considered under some circumstances, special caution should be used in applying any records to very small drainage areas with small storage capacity.

1. Inaccuracy which may result from basing the estimate of required storage for highly developed sources on records extending from 1908 to 1911 or 1912, instead of to 1914 or later.

The statistics were in most cases collected only from 1908 to the end of February, 1912, as these years represent the extremely dry period. With a drainage area developed with an extremely large amount of storage this period is too short to give correct results in eastern Massachusetts and in Rhode Island. For instance, when the records of the Wachusett Reservoir were available only to February, 1912, the amount of storage required to provide for a daily draft of 1 050 000 gal. per day per square mile of land surface was computed to be 338 million gal. After the records became available to the end of January, 1914, the required amount of storage was computed to be 394 million gal. The 338 million gal. first determined would by the revised table correspond to a daily draft of 1 023 000 instead of 1 050 000 gal., a difference of 2.6 per cent.

In New York and in New England west of the Connecticut River, there is probably little or no inaccuracy from this cause, as the dry period was ended abruptly by very heavy precipitation in the month of October, 1911.

2. Inaccuracy due to using some records which do not represent the driest period of years.

Among the capacity tables given are those based on the Croton records of 1908–1913, which is known not to represent as dry a period as the years 1879–1883, for the same drainage area.

There are no records to show whether or not the Waterbury records represent a period of extreme drought, but from the nearness of the Waterbury to the Croton drainage area it is likely that

they do not include the driest period which has occurred within the last sixty years.

As the Sudbury records for 1908–1912 do not appear to be trustworthy, a capacity table has been based upon the records for the years 1879–1884, although the yield during this period was somewhat greater than during the later period.

If the tables mentioned are used, some deduction should be made from the computed daily quantity if it is desired to obtain the safe capacity of the source for a period corresponding to the driest that has occurred in the past sixty years. This statement relates mainly to highly developed drainage areas.

3. Inaccuracy due to basing computations on monthly instead of daily yield.

When the critical period used in computing the capacity tables extends over only a few months there is often an inaccuracy arising from the use of monthly instead of daily records, because the month preceding or that succeeding the critical period, although giving a high average yield, may contain a number of days of very low yield which affect the amount of storage capacity required, and if these days had entered into the computation the required amount of storage corresponding to a given daily draft would be increased. This source of inaccuracy has a diminishing importance as the length of the critical period increases, but it is advisable in every case in making computations to assume as *available* storage less than the whole amount. It is better to adopt the safer policy of assuming that a month's supply of water, even though available for use, is not to be reckoned as available storage when making computations.

4. Inaccuracy resulting from deducing yields of land surfaces in short dry periods from records of drainage areas having large reservoirs.

When an attempt is made to obtain the yield from land surfaces during a period of very dry months from a drainage area like the Wachusett and from others having large reservoirs, it is necessary to make a large correction for evaporation, which as applied to individual months is uncertain in amount. In addition, the water in a reservoir which is in use lowers a considerable distance during such dry months, and some water is then draining from the inter-

stices of the ground into the reservoir of which no account is taken in the records.

To avoid inaccuracies due to these causes one should, for determining the safe capacity of sources with small reservoirs and small water surfaces, use the tables deduced from drainage areas having such reservoirs and water surfaces.

5. Inaccuracy due to assumption that the recent period of dry years includes the driest period of only a few months.

This report deals as a rule with the dry period 1879–1884 and the recent dry period beginning in 1908. The Manhan River records show that drier months occurred in 1900 than during the recent dry period, and these months have been used in preparing the table for that drainage area. It is not unlikely that in the years for which records are not available there are some drier short periods than have been used as a basis for the tables, but it is not probable that there have been even short periods very much drier than those upon which the tables are based.

In addition to the possible inaccuracies above enumerated, it is well for the engineer to be very conservative in applying any records to a very small drainage area with small storage capacity. This is not because there will not be, in the long run, substantially the same precipitation and the same amount of run-off per square mile from the small drainage area as from a large one, but because of the many uncertainties connected with a drainage area of less than, say, one square mile. The size of such an area may be somewhat indeterminate, especially if it is flat, because the watershed boundary of the ground water may not coincide with the limits of the superficial watershed.

A deficiency of precipitation may be somewhat more pronounced upon a small drainage area than upon a large one, because upon the larger area there may be showers which affect parts of the drainage area even though they do not affect the whole, while such showers may or may not fall on a small drainage area.

Of greater importance, however, is the amount of water which may be lost by percolation underground or by leakage past a dam. Such percolation or leakage, which would represent only a very small part of the yield of a large drainage area, may represent an important part of the yield of a small area.

The chances are, therefore, that the quantity of water which can be *depended upon* from a small drainage area in an extremely dry period will be materially less in proportion to the size than from a large one.

TABLE 11.

CAMBRIDGE WATER WORKS, STONY BROOK, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity, Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	4.6	14.6	25.3
100 000	6.1	12.9	22.5	34.4
150 000	15.1	22.1	31.7	43.6
200 000	24.3	31.3	42.4	53.7
250 000	34.4	41.9	53.1	64.4
300 000	45.2	52.7	63.8	75.1
350 000	56.4	64.9	74.5	85.8
400 000	68.6	77.2	86.0	107.0
450 000	80.9	89.4	109.0	134.0
500 000	93.1	113.0	137.0	170.0
550 000	115.0	140.0	184.0	232.0
600 000	150.0	199.0	246.0	295.0
650 000	212.0	261.0	308.0	357.0
700 000	275.0	323.0	371.0	419.0
750 000	340.0	388.0	435.0	483.0
800 000	409.0	457.0	503.0	
850 000	477.0	525.0		
900 000	546.0			

The amounts of storage given by this table are probably somewhat excessive even for drainage areas at a low elevation near the coast line, as there are extensive swamps on the drainage area of which no account was taken when computing the loss by evaporation, and there were other small losses from leakage and otherwise which are not accounted for in the records.

TABLE 12.

PAWTUCKET WATER WORKS, ABBOTT RUN, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	2.6	11.6	22.5
100 000	1.8	7.4	16.8	28.7
150 000	5.5	14.9	24.5	34.8
200 000	13.2	22.7	32.1	41.8
250 000	20.8	30.3	39.8	49.4
300 000	29.4	38.7	48.0	59.8
350 000	38.6	47.8	57.3	72.0
400 000	47.8	57.0	69.6	84.3
450 000	57.0	66.9	81.8	97.3
500 000	66.2	79.1	94.1	111.0
550 000	76.4	91.6	108.0	135.0
600 000	90.3	108.0	135.0	164.0
650 000	108.0	137.0	164.0	202.0
700 000	137.0	166.0	206.0	246.0
750 000	169.0	209.0	250.0	290.0
800 000	213.0	253.0	294.0	337.0
850 000	257.0	298.0	343.0	399.0
900 000	301.0	351.0	406.0	462.0
950 000	357.0	413.0	468.0	536.0
1 000 000	419.0	484.0	551.0	
1 050 000	501.0			

TABLE 13.

METROPOLITAN WATER WORKS, SUDBURY RIVER, 1879–1884.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	2.9	10.0
100 000	0.4	0.7	5.9	13.0
150 000	2.0	3.8	9.5	18.0
200 000	5.7	9.2	16.1	25.2
250 000	14.9	19.5	24.1	35.7
300 000	25.4	30.2	37.0	46.2
350 000	36.7	40.9	47.7	56.9
400 000	49.0	52.4	58.4	68.4
450 000	61.2	64.7	70.3	80.6
500 000	73.5	76.9	82.6	92.9
550 000	85.8	89.2	95.8	105.0
600 000	98.0	103.0	110.0	125.0
650 000	110.0	117.0	131.0	156.0
700 000	124.0	138.0	161.0	187.0
750 000	153.0	169.0	192.0	223.0
800 000	183.0	199.0	238.0	307.0
850 000	214.0	255.0	322.0	390.0
900 000	271.0	338.0	405.0	
950 000	357.0	422.0		
1 000 000	442.0			

TABLE 14.

METROPOLITAN WATER WORKS, SUDBURY RIVER, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity, Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	3.9	13.0	22.0
100 000	3.4	10.1	19.2	28.2
150 000	9.5	17.0	25.3	34.3
200 000	18.4	24.7	32.1	40.5
250 000	27.6	33.9	40.8	47.7
300 000	36.8	43.1	50.0	56.9
350 000	46.0	52.3	59.2	68.8
400 000	56.4	62.0	71.3	81.1
450 000	67.1	74.2	83.5	96.1
500 000	77.8	86.5	99.6	125.0
550 000	89.2	105.0	129.0	156.0
600 000	110.0	134.0	167.0	203.0
650 000	143.0	178.0	219.0	267.0
700 000	189.0	234.0	282.0	331.0
750 000	235.0	298.0	346.0	395.0
800 000	314.0	362.0	410.0	
850 000	381.0	428.0		
900 000	448.0			

TABLE 15.

METROPOLITAN WATER WORKS, WACHUSETT RESERVOIR, 1908–1914.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	2.7	10.8
100 000	0	0.2	5.8	15.4
150 000	0	3.0	9.9	20.0
200 000	1.3	6.1	14.5	24.6
250 000	4.1	10.6	20.1	32.0
300 000	8.7	16.7	26.2	39.6
350 000	15.1	23.3	33.0	47.3
400 000	23.2	31.3	40.7	54.9
450 000	32.4	40.5	49.1	62.6
500 000	41.6	49.7	58.3	71.2
550 000	50.8	58.9	67.6	80.9
600 000	60.0	68.1	81.4	104.0
650 000	69.2	81.4	104.0	130.0
700 000	82.0	104.0	127.0	156.0
750 000	106.0	128.0	153.0	182.0
800 000	131.0	153.0	179.0	208.0
850 000	155.0	177.0	205.0	254.0
900 000	180.0	208.0	261.0	350.0
950 000	210.0	275.0	365.0	454.0
1 000 000	290.0	379.0	468.0	557.0
1 050 000	394.0	483.0	572.0	
1 100 000	497.0	586.0		
1 150 000	601.0			

TABLE 16.

WORCESTER, TATNUCK BROOK, 1908–FEBRUARY, 1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0.8	4.3	8.2
100 000	0	2.4	5.9	12.3
150 000	0	3.9	10.2	18.5
200 000	2.0	8.1	16.3	24.6
250 000	6.0	11.3	22.5	30.8
300 000	12.2	20.4	28.7	39.7
350 000	19.0	26.6	37.3	48.9
400 000	26.6	34.9	46.5	58.0
450 000	34.3	44.1	55.6	67.2
500 000	43.4	53.7	64.8	76.3
550 000	54.1	64.4	74.9	85.4
600 000	64.8	75.1	85.6	95.9
650 000	75.5	85.8	96.3	107.0
700 000	86.2	96.5	107.0	117.0
750 000	97.0	107.0	118.0	138.0
800 000	109.0	118.0	135.0	164.0
850 000	122.0	132.0	161.0	198.0
900 000	134.0	158.0	195.0	240.0
950 000	155.0	192.0	238.0	283.0
1 000 000	188.0	234.0	280.0	326.0
1 050 000	232.0	277.0	325.0	387.0
1 100 000	276.0	326.0	387.0	
1 150 000	326.0	388.0		
1 200 000	388.0			

TABLE 17.

HOLYOKE WATER WORKS, MANHAN RIVER, 1900, 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity, Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	2.0	6.4	12.7
100 000	0.6	3.8	10.5	18.1
150 000	2.1	8.4	15.1	25.7
200 000	6.8	13.7	22.7	33.4
250 000	12.9	19.8	30.4	41.0
300 000	19.1	27.4	38.0	48.7
350 000	25.2	35.0	45.7	56.3
400 000	36.9	42.8	53.3	64.0
450 000	49.1	54.9	61.0	71.6
500 000	61.2	67.1	72.9	79.3
550 000	73.4	79.2	85.1	90.9
600 000	85.5	91.4	97.2	103.0
650 000	97.7	104.0	109.0	116.0
700 000	110.0	116.0	122.0	139.0
750 000	122.0	128.0	145.0	162.0
800 000	134.0	151.0	168.0	185.0
850 000	157.0	174.0	191.0	208.0
900 000	180.0	197.0	213.0	231.0
950 000	203.0	220.0	236.0	256.0
1 000 000	226.0	243.0	260.0	292.0
1 050 000	249.0	266.0	303.0	353.0
1 100 000	272.0	315.0	364.0	414.0
1 150 000	326.0	376.0	425.0	
1 200 000	387.0	437.0		
1 250 000	448.0			

TABLE 18.

WESTFIELD, TILLOTSON BROOK,* 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	4.0	10.1
100 000	0	1.2	6.9	15.7
150 000	0	4.2	13.0	21.9
200 000	1.7	10.3	19.2	28.0
250 000	7.7	16.5	25.3	34.2
300 000	13.9	22.6	31.5	40.3
350 000	20.0	28.8	37.6	46.5
400 000	26.2	34.9	43.8	52.6
450 000	32.3	41.1	50.0	58.8
500 000	38.6	47.2	56.1	64.9
550 000	50.8	58.0	65.2	72.4
600 000	62.9	70.2	77.3	84.6
650 000	75.1	82.4	89.4	106.0
700 000	87.2	94.5	111.0	128.0
750 000	99.4	116.0	133.0	151.0
800 000	121.0	139.0	156.0	174.0
850 000	144.0	161.0	179.0	197.0
900 000	166.0	184.0	203.0	238.0
950 000	189.0	210.0	247.0	296.0
1 000 000	212.0	259.0	308.0	357.0
1 050 000	271.0	320.0	369.0	418.0
1 100 000	332.0	381.0	430.0	
1 150 000	393.0	442.0		
1 200 000	454.0			

* For later figures see note on page 471.

TABLE 19.

WATERBURY WATER WORKS, WEST BRANCH OF NAUGATUCK RIVER, 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.6	8.3	20.0	31.7
100 000	5.2	14.3	26.1	37.8
150 000	9.8	20.4	32.2	44.0
200 000	16.8	27.0	38.3	50.0
250 000	24.5	34.6	45.2	56.2
300 000	32.2	43.2	54.4	65.3
350 000	41.4	52.3	63.5	74.5
400 000	51.6	61.5	72.7	83.6
450 000	62.3	72.1	82.2	92.8
500 000	73.0	82.8	92.9	103.0
550 000	83.7	93.5	104.0	114.0
600 000	94.4	104.0	114.0	124.0
650 000	105.0	115.0	125.0	135.0
700 000	116.0	126.0	136.0	146.0
750 000	127.0	136.0	146.0	158.0
800 000	137.0	147.0	161.0	181.0
850 000	148.0	165.0	184.0	212.0
900 000	168.0	187.0	215.0	255.0
950 000	191.0	218.0	257.0	304.0
1 000 000	221.0	261.0	312.0	365.0
1 050 000	265.0	319.0	372.0	427.0
1 100 000	326.0	380.0	436.0	
1 150 000	389.0	444.0		
1 200 000	453.0			

TABLE 20.

HARTFORD RESERVOIRS, JUNE, 1909–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	5.4	17.6	31.1
100 000	1.6	11.9	25.2	38.7
150 000	6.8	19.6	32.9	46.4
200 000	13.8	27.2	40.5	54.0
250 000	21.4	34.9	48.2	61.6
300 000	29.3	42.5	55.8	69.3
350 000	38.4	50.7	63.5	77.0
400 000	47.6	59.8	72.1	84.6
450 000	56.7	69.0	81.3	93.7
500 000	65.9	78.2	90.4	103.0
550 000	75.0	87.3	99.6	112.0
600 000	84.2	96.4	109.0	121.0
650 000	93.3	106.0	118.0	136.0
700 000	104.0	115.0	133.0	162.0
750 000	115.0	131.0	159.0	188.0
800 000	129.0	157.0	185.0	223.0
850 000	154.0	183.0	222.0	266.0
900 000	180.0	221.0	264.0	308.0
950 000	220.0	263.0	307.0	
1 000 000	262.0	306.0		
1 050 000	306.0			

TABLE 21.

New York Water Works, Croton River, 1879–1883.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	3.6	9.4	15.3
100 000	1.4	6.6	12.4	20.7
150 000	3.9	9.7	17.1	26.8
200 000	9.5	14.2	23.9	33.0
250 000	16.5	24.0	31.6	42.4
300 000	27.2	34.7	42.9	54.1
350 000	37.9	45.4	55.1	66.4
400 000	48.8	56.1	67.4	78.6
450 000	61.0	68.4	79.6	90.9
500 000	73.3	80.6	91.9	103.0
550 000	85.8	94.4	104.0	115.0
600 000	99.6	108.0	117.0	128.0
650 000	113.0	122.0	131.0	140.0
700 000	127.0	136.0	144.0	153.0
750 000	141.0	150.0	158.0	167.0
800 000	155.0	163.0	172.0	186.0
850 000	173.0	188.0	202.0	222.0
900 000	203.0	218.0	253.0	300.0
950 000	243.0	290.0	337.0	384.0
1 000 000	327.0	374.0	420.0	467.0
1 050 000	410.0	457.0		
1 100 000	494.0			

TABLE 22.

NEW YORK WATER WORKS, CROTON RIVER, 1908–1913.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.3	2.1	6.2	16.0
100 000	1.8	4.3	12.3	22.1
150 000	3.6	8.6	18.5	28.3
200 000	6.6	14.8	24.6	34.4
250 000	11.1	20.9	30.8	40.6
300 000	18.4	27.1	36.9	46.7
350 000	27.6	35.0	43.1	52.9
400 000	36.8	44.2	51.7	59.1
450 000	46.0	53.4	60.9	68.3
500 000	55.2	62.6	70.1	78.1
550 000	64.4	71.8	79.3	88.8
600 000	73.6	81.0	88.5	99.5
650 000	82.8	90.2	98.9	110.0
700 000	92.0	99.4	110.0	124.0
750 000	102.0	111.0	129.0	149.0
800 000	117.0	134.0	153.0	173.0
850 000	139.0	159.0	178.0	197.0
900 000	164.0	183.0	202.0	235.0
950 000	188.0	209.0	253.0	296.0
1 000 000	226.0	270.0	314.0	357.0
1 050 000	287.0	331.0	375.0	417.0
1 100 000	348.0	392.0	436.0	
1 150 000	409.0			

This table does not represent as dry a period as the preceding one based on the run-off for the years 1879–1883, and consequently has little value.

TABLE 23.

New York Water Works, Esopus Creek, 1908–1913.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	1.9	5.6	9.9
100 000	0	3.5	8.1	13.0
150 000	2.2	6.6	11.2	16.0
200 000	5.3	9.7	16.4	23.6
250 000	9.7	17.0	24.0	31.2
300 000	17.4	24.6	31.7	38.9
350 000	25.1	32.3	39.3	46.5
400 000	32.8	40.0	47.0	54.2
450 000	41.4	47.6	54.6	61.8
500 000	50.6	55.6	62.3	69.5
550 000	59.8	64.8	69.9	77.1
600 000	69.0	74.0	79.1	84.8
650 000	78.2	83.2	88.3	93.5
700 000	87.4	92.4	97.5	103.0
750 000	96.6	102.0	107.0	112.0
800 000	106.0	111.0	116.0	121.0
850 000	115.0	120.0	125.0	132.0
900 000	124.0	129.0	135.0	142.0
950 000	133.0	138.0	145.0	153.0
1 000 000	143.0	148.0	156.0	177.0
1 050 000	152.0	159.0	173.0	203.0
1 100 000	162.0	170.0	199.0	228.0
1 150 000	173.0	196.0	225.0	254.0
1 200 000	193.0	222.0	251.0	280.0
1 250 000	218.0	248.0	277.0	306.0
1 300 000	244.0	274.0	303.0	332.0
1 350 000	270.0	299.0	328.0	374.0
1 400 000	296.0	325.0	370.0	435.0

This table gives a smaller amount of storage, and consequently a larger daily quantity, than should be adopted in practice, for the reason that the extreme drought which occurred in New England was not so severe upon this drainage area, and the further reason that the measurements of the discharge of Esopus Creek on account of ice conditions were not as precise as they will be in the future when the reservoirs will be filled and the effect of such conditions will not be felt.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.

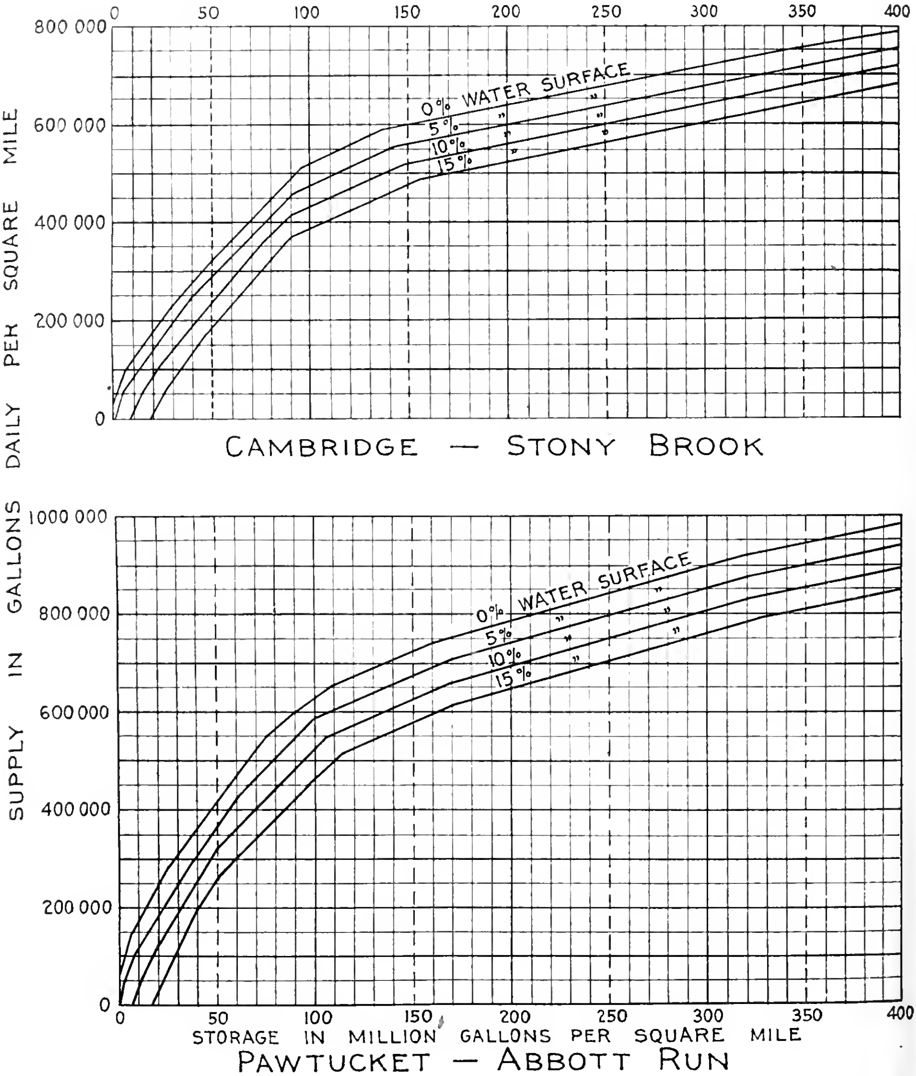


Fig. 1.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface

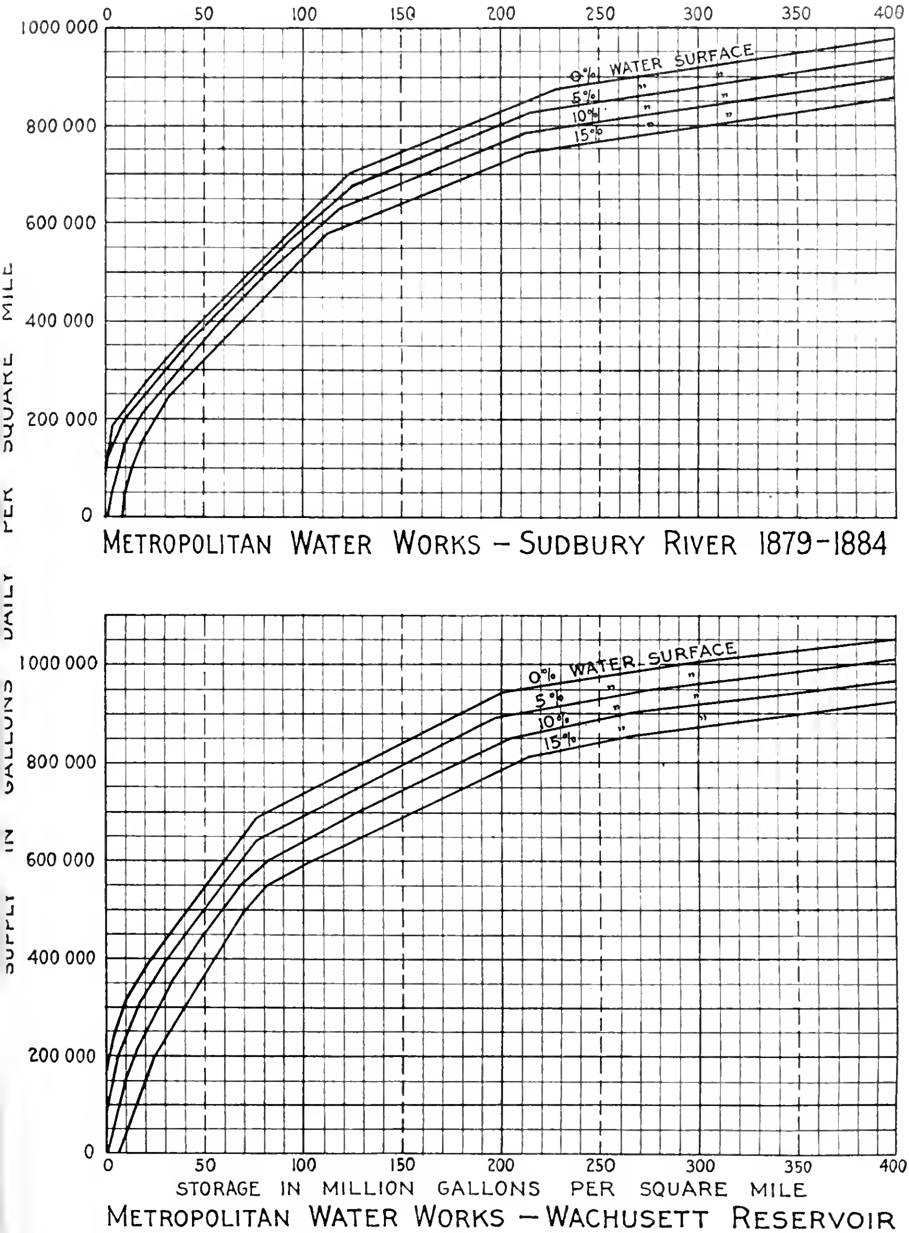


Fig. 2.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.

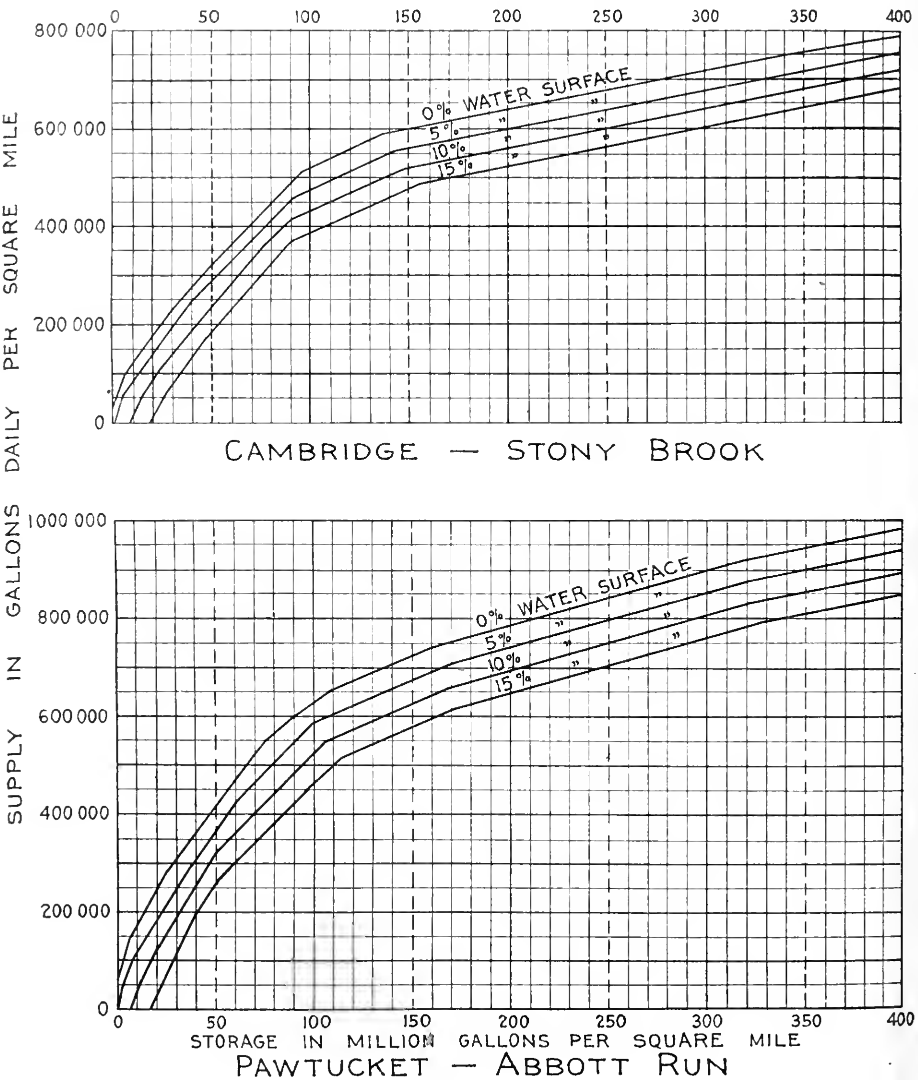


Fig. 1.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface

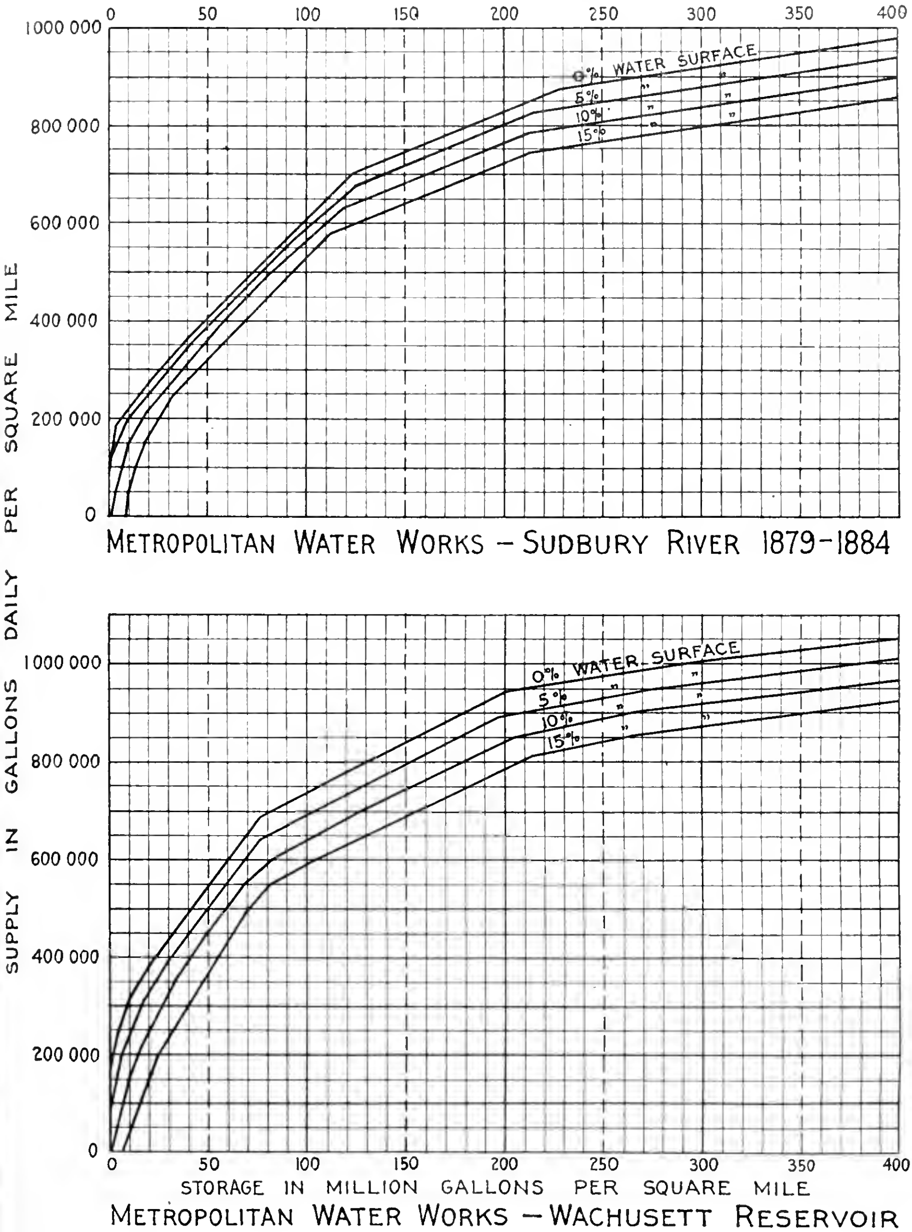


Fig. 2.

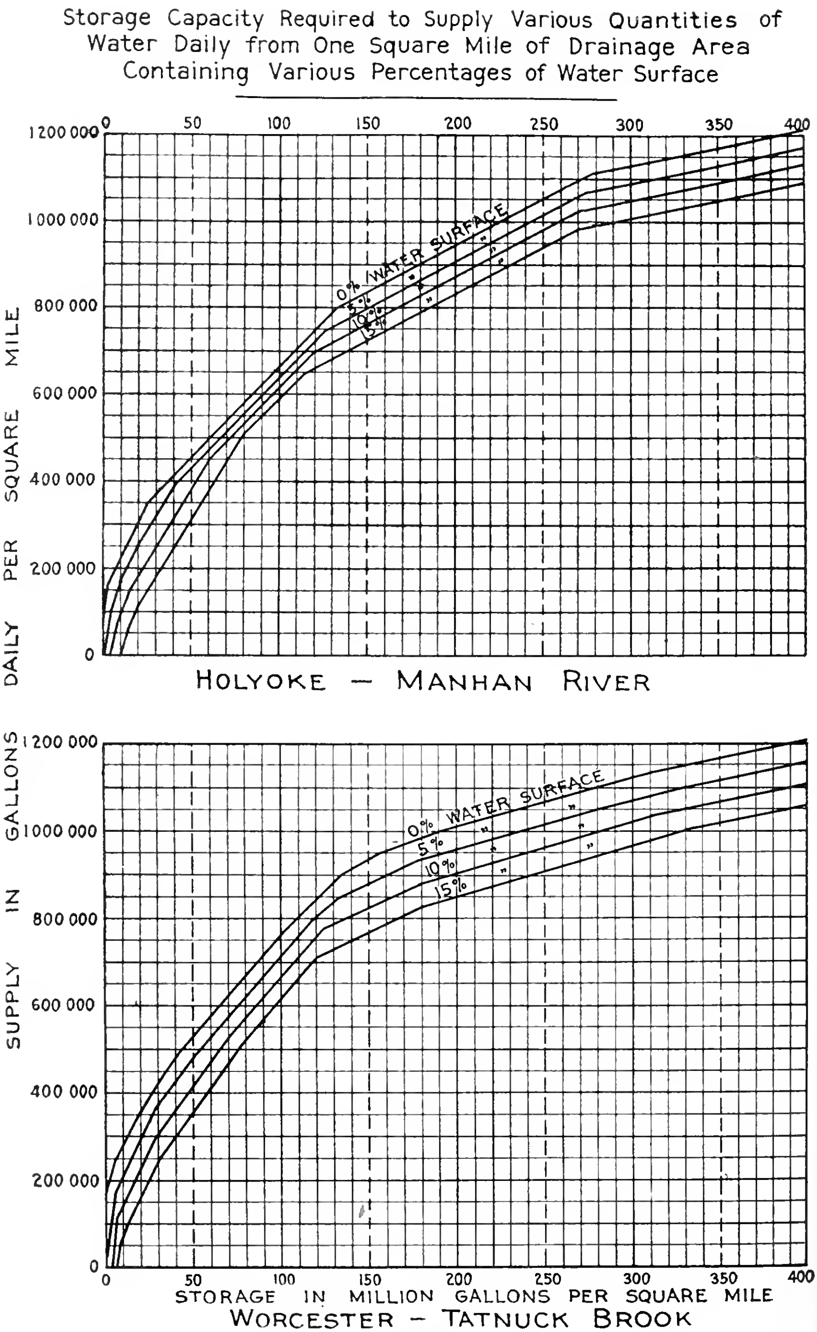

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface
0
50
100
150
200
250
300
350
400
1200 000
1 000 000
800 000
600 000
400 000
200 000
0
0% WATER SURFACE
5%
10%
15%
DAILY SUPPLY IN GALLONS PER SQUARE MILE
HOLYOKE — MANHAN RIVER
1 200 000
1 000 000
800 000
600 000
400 000
200 000
0
0% WATER SURFACE
5%
10%
15%
0
50
100
150
200
250
300
350
400
STORAGE IN MILLION GALLONS PER SQUARE MILE
WORCESTER — TATNUCK BROOK

FIG. 3.

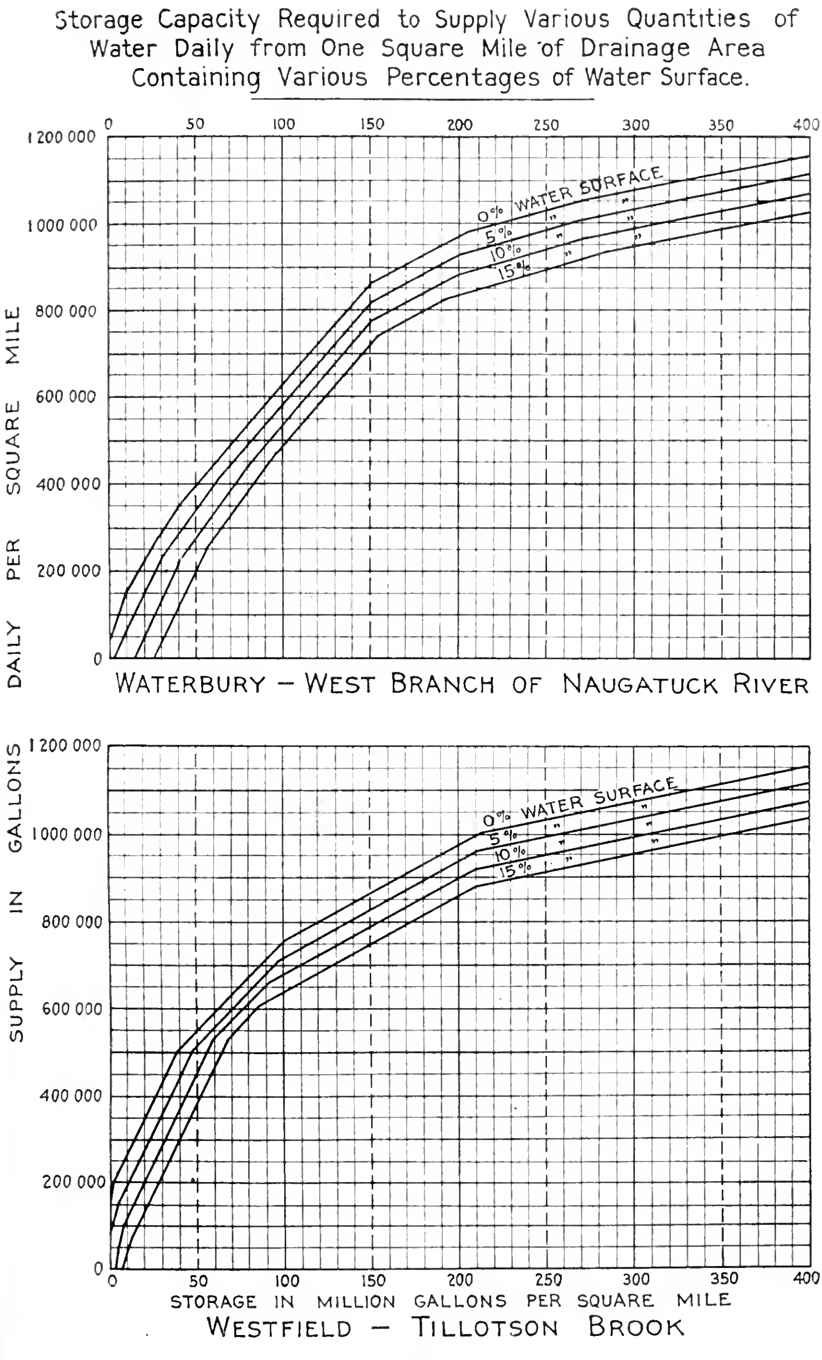

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.
0% WATER SURFACE
5%
10%
15%
WATERBURY — WEST BRANCH OF NAUGATUCK RIVER
DAILY SUPPLY IN GALLONS PER SQUARE MILE
STORAGE IN MILLION GALLONS PER SQUARE MILE
WESTFIELD — TILLOTSON BROOK
0
50
100
150
200
250
300
350
400
200 000
400 000
600 000
800 000
1 000 000
1 200 000

Fig. 4.

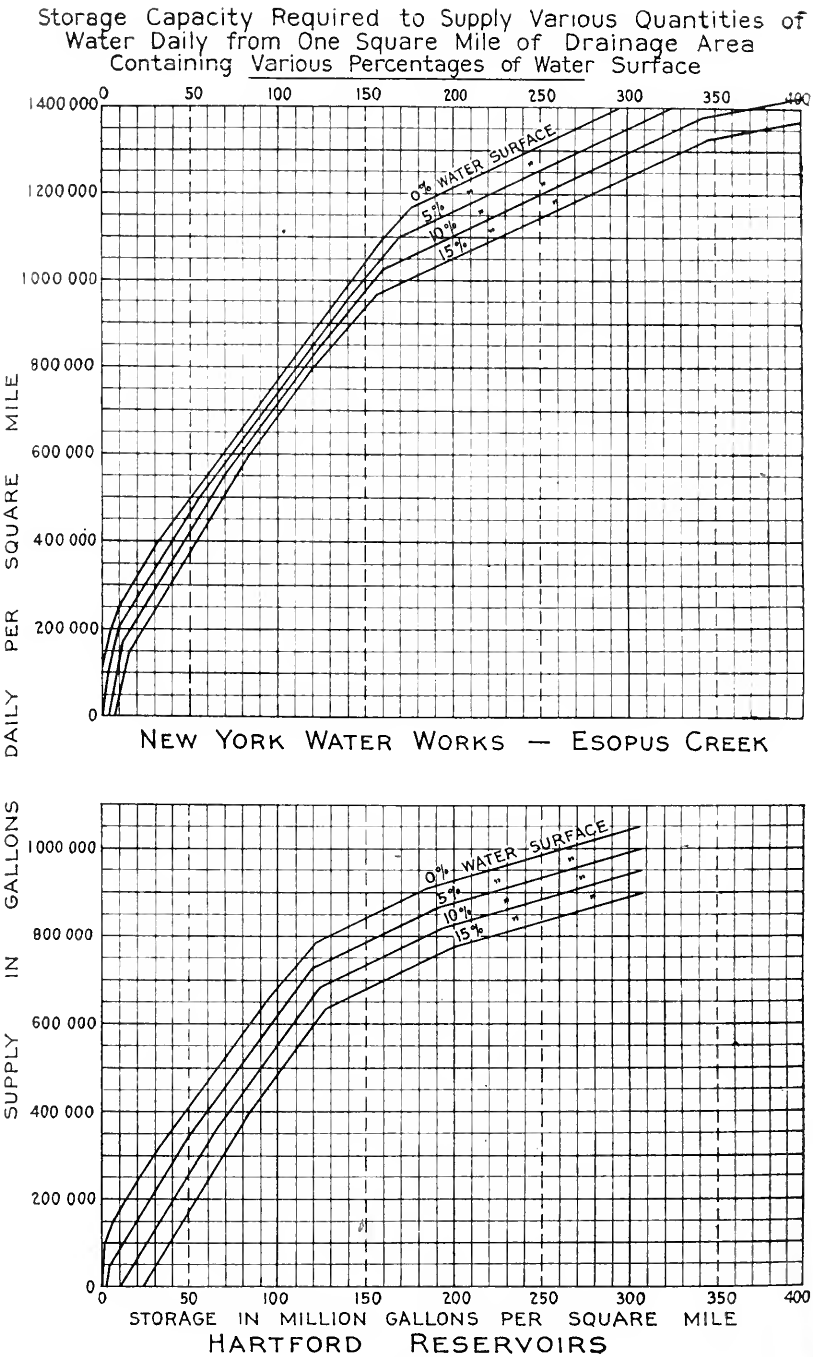

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface
0% WATER SURFACE
5%
10%
15%
NEW YORK WATER WORKS — ESOPUS CREEK
0% WATER SURFACE
5%
10%
15%
DAILY SUPPLY IN GALLONS PER SQUARE MILE
STORAGE IN MILLION GALLONS PER SQUARE MILE
HARTFORD RESERVOIRS

FIG. 5.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.

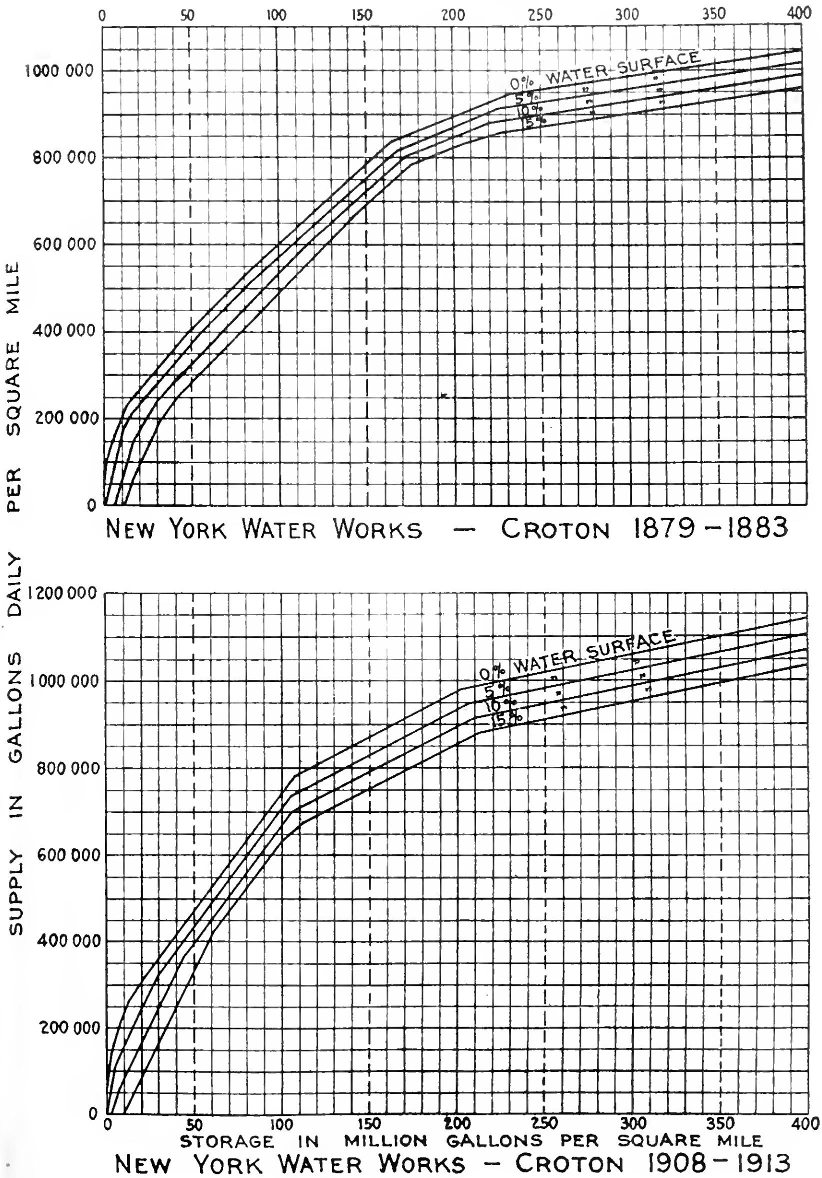


Fig. 6.

HOW TO USE THE "CAPACITY TABLES" AND DIAGRAMS FOR COMPUTING THE SAFE CAPACITY OF SOURCES OF WATER SUPPLY.

In order to apply practically the series of capacity tables or the diagrams showing the storage capacity required to supply different daily drafts of water from one square mile of drainage area, it is necessary to have the following preliminary information:

1. Drainage area in square miles.
2. The area of water surfaces when the reservoirs are full, in square miles.
3. The available capacity of the storage reservoir, in million gallons.

In addition, the mean elevation of the drainage area above the sea is desirable.

In determining the area of water surfaces when the most accurate results are desired, they should include not only the area of the water supply reservoir or reservoirs, but of all other water surfaces, and should also include 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps.

By dividing the total area of water surfaces so determined by the number of square miles in the drainage area, the per cent. of water surfaces when the reservoirs are full is obtained.

The *available* capacity of the storage reservoir divided by the number of square miles in the whole drainage area gives the storage per square mile.

Several examples of the application of the tables and diagrams will be given. The first assumes a drainage area with only a small amount of storage, so that the storage reservoir is filled every spring and is liable to be exhausted by a drought of not more than six months' duration. It will be assumed that this source is located in Massachusetts, west of the Connecticut River, where the average elevation of the drainage area is 900 ft. above sea level. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces..........	20 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps..	0.25 sq. mile.
Assumed available storage capacity.....................	520 mil. gal.
Water surfaces, $0.25 \div 20 =$	1.25 per cent.
Available storage per sq. mile of drainage area, $520 \div 20 =$ ..	26 mil. gal.

The safe daily capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 24.

EXAMPLE OF USE OF CAPACITY TABLES — SMALL STORAGE.

Drainage Area.	Elevation above Sea Level, Feet	Safe Capacity in Gallons per Day. 1 Sq. Mile.	20 Sq. Miles.
Cambridge, Stony Brook	180	200 000	4 000 000
Metropolitan Water Works: Sudbury River, 1908–1912	300	233 000	4 660 000
Waterbury, Naugatuck River	890	243 000	4 860 000
Hartford Reservoirs	460	258 000	5 160 000
Pawtucket, Abbott Run	150	266 000	5 320 000
New York Water Works: Croton River, 1879–1883	620	286 000	5 720 000
Metropolitan Water Works: Sudbury River, 1879–1884	300	297 000	5 940 000
Holyoke, Manhan River	950	337 000	6 740 000
New York Water Works: Esopus Creek	1 700	344 000	6 880 000
Worcester, Tatnuck Brook	950	383 000	7 660 000
Westfield, Tillotson Brook	990	387 000	7 740 000
Metropolitan Water Works: Wachusett Reservoir	750	404 000	8 080 000
Average		303 000	

In former years when estimates of the safe capacity of a source were based mainly upon the Sudbury River records of 1879–1883, computations like those above indicated gave a single result which might be accepted as the safe capacity of the proposed source, or might be modified for various reasons in accordance with the judgment of the engineer making the computations. Now that the records of many drainage areas are available, there is a wide variation in the results, especially when the amount of storage is small.

In the example given above, the amount of storage is so small that the reservoir would be sure to fill and overflow each spring, and if drawn upon to the extent of its safe capacity would reach its lowest point within six months of the time when the water ceased to run over the spillway.

For such short periods as this, the records of the run-off from different drainage areas are very varied, as the run-off at such times depends both upon the precipitation during the dry period and upon the amount of water stored in the interstices of the ground during the wet season which finds it way into the streams during the dry period.

One or two heavy showers or rains on any given drainage area during such a dry period materially affect the results, and although it is well known that the relative precipitation in a series of years upon different drainage areas is nearly uniform, there is no such uniformity during short periods.

Referring again to the example given above of a drainage area with small water surfaces, the capacity tables based upon drainage areas containing large water surfaces — like the Wachusett, Sudbury, Worcester, and Hartford sources — are not strictly applicable because of the unavoidable inaccuracy in making estimates of the evaporation from the large water surfaces for any given short period.

There is also another source of inaccuracy in such cases, — that the extremely dry period of six months or less, which really serves as a basis for determining the smaller figures of storage in the capacity tables, corresponds to a period when the large reservoirs are lowering rapidly, and some water is draining from the ground into the reservoir of which no account is taken in the records. The Wachusett Reservoir during the six months' period which served as a basis for the results in the foregoing example lowered 14 ft.

Reverting now to the table giving the safe capacity of the assumed source on the basis of the different capacity tables, it is well to omit on general principles the results based on Stony Brook, Sudbury River 1908–1912, and Esopus Creek, and on account of large water surfaces to omit also the results based on the Hartford Reservoirs, Tatnuck Brook, and Wachusett Reservoir. With these omissions, the safe capacity per square mile of drainage area ranges from 243 000 gal. daily on the basis of the Naugatuck River table to 387 000 gal. daily on the basis of the Tillotson Brook table. The average of all the results not excluded gives 303 000 gal. daily per sq. mile, equivalent to 6 060 000 gal. daily for

the whole drainage area. On the basis of the Naugatuck River, the safe capacity of this drainage area would be 4 860 000 gal. daily.

Whether, in a case like this, one should adopt 5 000 000 or 6 000 000 gal. daily as the safe capacity of the source will depend upon circumstances. If, as suggested in the statement immediately preceding the capacity tables, provision has been made for storage equivalent to the daily draft for a month, as a reserve which is not included in the available storage upon which the estimates of safe capacity have been based, there is more reason for adopting the larger figure than if this precaution had not been taken.

The yield of drainage areas for short periods is, as indicated by the results obtained, very variable, and as a small storage reservoir of this kind is drawn to a low level nearly every year and does not give much warning as to when it may be exhausted, it is desirable to be conservative and to adopt the lower estimate, unless it is known that there is an emergency supply which can quickly be made available.

The elevation above sea level does not seem to be an important factor when the storage is so small that it will tide over only a few dry months.

The second example assumes a drainage area situated in Massachusetts between the Wachusett and Abbott Run drainage areas, at a place where the average elevation of the assumed drainage area is 400 ft. above sea level. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces........	30 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps..................................	1 sq. mile.
Assumed available storage capacity....................	3 900 mil. gal.
Water surfaces, $1 \div 30 =$	3.33 per cent.
Available storage per square mile of drainage area, $3\,900 \div 30 =$	130 mil. gal.

The safe capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 25.

EXAMPLE OF USE OF CAPACITY TABLES—MEDIUM STORAGE.

Drainage Area.	Elevation above Sea Level. Feet.	Safe Capacity in Gallons per Day.	
		1 Sq. Mile.	30 Sq. Miles.
Cambridge, Stony Brook......	180	547 000	16 410 000
Metropolitan Water Works:			
Sudbury River, 1908–1912 ..	300	605 000	18 150 000
Pawtucket, Abbott Run.......	150	655 000	19 650 000
New York Water Works:			
Croton River, 1879–1883 ...	620	689 000	20 670 000
Metropolitan Water Works:			
Sudbury River, 1879–1884....	300	691 000	20 730 000
Waterbury, Naugatuck River..	890	735 000	22 050 000
Holyoke, Manhan River..........	950	760 000	22 800 000
Hartford Reservoirs............	460	760 000	22 800 000
Metropolitan Water Works:			
Wachusett Reservoir..........	750	769 000	23 070 000
Westfield, Tillotson Brook	990	793 000	23 790 000
Worcester, Tatnuck Brook......	950	853 000	25 590 000
New York Water Works:			
Esopus Creek..................	1 700	915 000	27 450 000
Average....................		731 000	

In this case, after omitting the results based on Stony Brook, Sudbury River 1908–1912, and Esopus Creek, the computed capacities do not vary nearly as much as in the first example. One reason for this is that the assumed storage capacity is so large that the critical period upon which the computations of storage are based extends from the spring or early summer of 1910 to the autumn of 1911, and in so long a period the irregularities of precipitation are much less than during short periods.

As a matter of interest, one may average the quantities given in the table, with the exceptions noted, and obtain as a result a safe capacity per square mile of 745 000 gal. per day. This does not give the best results, however, because all of the drainage areas with the exception of Abbott Run have a greater elevation than the assumed drainage area, with a consequent higher precipitation and run-off.

Better results would be obtained in this case by using the results based upon the Abbott Run and Wachusett drainage areas, between which the assumed drainage area is located, and by giving due

weight to the relative elevations of the drainage areas. The Abbott Run drainage area is 150 ft. above sea level, and upon the basis of this source the safe capacity is 655 000 gal. daily per sq. mile. The Wachusett drainage area is 750 ft. above sea level, and upon the basis of this source the safe capacity is 769 000 gal. The assumed drainage area has an elevation of 400 ft. above sea level. By proportioning according to the relative elevations, the safe capacity of the assumed source is found to be 700 000 gal. daily per sq. mile, or 21 000 000 gal. daily for the whole drainage area. This appears to be a reasonable result.

The third example assumes the existence of a pond having a comparatively small drainage area, situated in Massachusetts at a place where the average elevation of the drainage area above sea level is 300 ft. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces.......	2 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps............................180 acres = 0.282	sq. mile.
Assumed available storage capacity..................	600 mil. gal.
Water surfaces, 0.282 ÷ 2 = ...	14.1 per cent.
Available storage per square mile of drainage area, 600 ÷ 2 =	300 mil. gal.

The safe daily capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 26.

EXAMPLE OF USE OF CAPACITY TABLES — LARGE STORAGE.

Drainage Area.	Elevation above Sea Level. Feet.	Safe Capacity in Gallons per Day.	
		1 Sq. Mile.	2 Sq. Miles.
Cambridge, Stony Brook...............	180	611 000	1 220 000
Metropolitan Water Works:			
Sudbury River, 1908–1912...........	300	683 000	1 370 000
Pawtucket, Abbott Run...............	150	768 000	1 540 000
Metropolitan Water Works:			
Sudbury River, 1879–1884...........	300	803 000	1 610 000
Wachusett Reservoir...............	750	881 000	1 760 000
New York Water Works:			
Croton River, 1879–1883............	620	905 000	1 810 000
Hartford Reservoirs..................	460	900 000	1 800 000
Waterbury, Naugatuck River..........	890	954 000	1 910 000
Westfield, Tillotson Brook.............	990	960 000	1 920 000
Worcester, Tatnuck Brook............	950	979 000	1 960 000
Holyoke, Manhan River..............	950	1 007 000	2 010 000
New York Water Works:			
Esopus Creek.......................	1 700	1 248 000	2 500 000
Average..........................		892 000	

The average, after omitting the records of Stony Brook, Sudbury River 1908–1912, and Esopus Creek, is 906 000 gal. per day per sq. mile, but the low elevation of the assumed drainage area would make the Abbott Run basis to a large extent controlling, and 800 000 gal. per sq. mile, equivalent to 1 600 000 gal. per day for the whole drainage area, would be a more reasonable quantity to adopt as the safe capacity of the source.

With so large a storage capacity per square mile as is assumed in this case, it would require three years or more to exhaust the reservoir. An extremely dry period, such as has recently occurred, is not likely to occur except after long intervals, and under ordinary conditions such a source would supply 1 800 000 or 1 900 000 gal. of water per day. It is an advantage of such a large amount of storage that a town may continue to use such a source until its water consumption is considerably above the so-called safe capacity of the source, because with so large a quantity of storage there is time to provide an additional supply after the source gives indication that it is insufficient.

TABLE 27.

EXAMPLE OF USE OF CAPACITY TABLES FOR OBTAINING SAFE CAPACITY OF WACHUSETT SUPPLY.

Drainage area, including water surfaces		118.19 sq. miles.
Water surfaces, exclusive of swamps	8.59 sq. miles.	
40 per cent. of 2.91 square miles of undrained swamps	1.16 sq. miles.	
30 per cent. of 0.68 square mile of drained swamps	0.20 sq. mile.	
Total area reckoned as water surfaces		9.95 sq. miles.
Water surfaces, 9.95 ÷ 118.19		8.42 per cent.
Total storage, Wachusett Reservoir (elevation 395.0)		64 968 mil. gal.
Storage below elevation 330, called unavailable		9 415 mil. gal.
Available storage		55 553 mil. gal.
Available storage per square mile, 55 553 ÷ 118.19		470 mil. gal.
Safe daily draft per square mile, obtained by interpolation from table for Wachusett drainage area		1 015 000 gal.
Total safe daily capacity, 1 015 000 × 118.19		120 000 000 gal.

The fourth example relates to the safe capacity of the Wachusett supply as it existed before the water from a part of the drainage area was diverted for the water supply of the city of Worcester. This supply was very highly developed for the purpose of improving the quality of the water and of providing surplus storage which could be utilized in connection with future additions to the supply.

Although the above table shows that a daily draft of a little more than 1 000 000 gal. per sq. mile could be obtained from the Wachusett drainage area as it is now developed, it is found, by referring to the detailed records, not only that the reservoir would not have filled with such a draft after June 1, 1908, but that it would have been at a lower level at the end of the dry period of each successive year, and would just have exhausted the available storage in the reservoir at the end of January, 1914. At the end of July, 1914, the amount of water stored would have been 2 624 mil. gal. more than at the corresponding date in 1913. What the future condition of the reservoir would be, with the assumed draft, cannot be foretold. A continuation of dry years would make still further demand upon it, while with average or wet years the water would rise.

COMPOSITE CAPACITY DIAGRAM.

It will be noted by reference to the capacity diagrams that they are composed of straight lines instead of curves, and similarly, in the capacity tables there will frequently be found constant differences between successive terms in a column. For instance, in Table 15, relating to the Wachusett drainage area, in the column headed 0 per cent., there is a constant difference of 9.2 between successive figures from 23.2 to 69.2 mil. gal. of required storage. The reason for this is that the yield during a certain six months was the critical period upon which all of the figures of storage between these limits were based.

The straight lines and constant differences mentioned are the result of basing the diagrams and tables on actual records of yield, and they consequently represent only approximately the general law affecting the relation between the amount of storage and the

safe daily capacity of the source. The general law is that as the amount of storage is increased, a larger increment of storage is required for a given increment in the safe capacity of the source; that is, by the general law the difference between successive figures of required storage in the tables should always be increasing instead of being constant in some parts of the tables.

As an illustration, reference is made to the first and second columns of Table 15, where the required storage corresponding to an increase of 50 000 gal. in the daily supply or safe capacity is as follows:

Increase in Daily Supply. Gallons.	Corresponding Increment in Required Storage. Million Gallons.
200 000 to 250 000	2.8
400 000 to 450 000	9.2
600 000 to 650 000	9.2
800 000 to 850 000	24.0
1 000 000 to 1 050 000	104.0

COMPOSITE DIAGRAM

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface

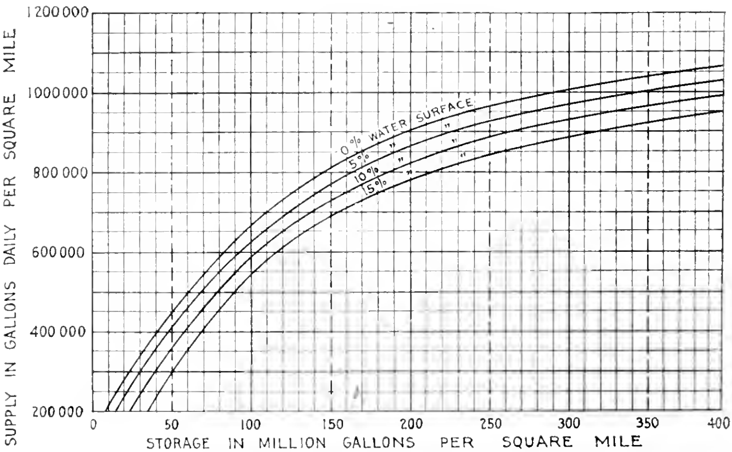


FIG. 7.

The illustration shows clearly that a very much larger quantity of storage is required to furnish an increment of 50 000 gal. in the daily supply when the supply, and consequently the storage, is large than when it is small, but it also shows what is not in accordance with the general law — that 9.2 mil. gal. storage is as effective in increasing the daily supply when it is 600 000 gal. as when it is 400 000 gal.

Notwithstanding this failure of the diagrams and tables to comply with the general law here pointed out, it has been thought best to keep them in the form in which they were computed, so that when used they will give the results which would obtain if there were a recurrence of the identical dry periods on which the tables and diagrams were based.

For some studies, however, it will be more useful to have a diagram which will represent more closely the general law, and a composite diagram (Fig. 7) is therefore presented, which is based upon the following diagrams: Abbott Run; Sudbury,

TABLE 28.

Table showing Increment in Storage Capacity Corresponding to Increment in Daily Supply from One Square Mile of Drainage Area containing Various Percentages of Water Surface Based upon Composite Diagram.

Increment in Daily Supply. Gallons.	Increment in Required Storage. Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
200 000 to 250 000	7.2	7.2	7.6	7.5
250 000 to 300 000	7.8	7.9	8.2	8.1
300 000 to 350 000	8.4	8.6	8.8	8.7
350 000 to 400 000	9.0	9.3	9.4	9.4
400 000 to 450 000	9.6	10.0	10.0	10.1
450 000 to 500 000	10.2	10.7	10.7	11.0
500 000 to 550 000	10.9	11.5	11.9	12.4
550 000 to 600 000	11.7	12.7	13.6	14.6
600 000 to 650 000	12.9	14.3	15.8	17.6
650 000 to 700 000	14.4	16.3	18.5	21.6
700 000 to 750 000	16.3	18.7	22.0	26.6
750 000 to 800 000	18.8	21.7	26.0	33.0
800 000 to 850 000	22.6	26.5	33.0	43.0
850 000 to 900 000	28.8	35.0	45.0	57.0
900 000 to 950 000	38.7	49.5	62.0	75.0
950 000 to 1 000 000	53.6	71.0	83.0	
1 000 000 to 1 050 000	74.8	103.0		

1879–1884; Wachusett; Manhan River; Tillotson Brook; Naugatuck River; Croton, 1879–1883; Croton, 1908–1913.

The preceding table is derived from the composite diagram, and shows the increment of required storage for each increment of 50 000 gal. daily of daily supply.

EFFECT OF A CONSTANT DAILY DRAFT FROM WACHUSETT RESERVOIR EQUAL TO SAFE CAPACITY OF SOURCE, 1897–1914.

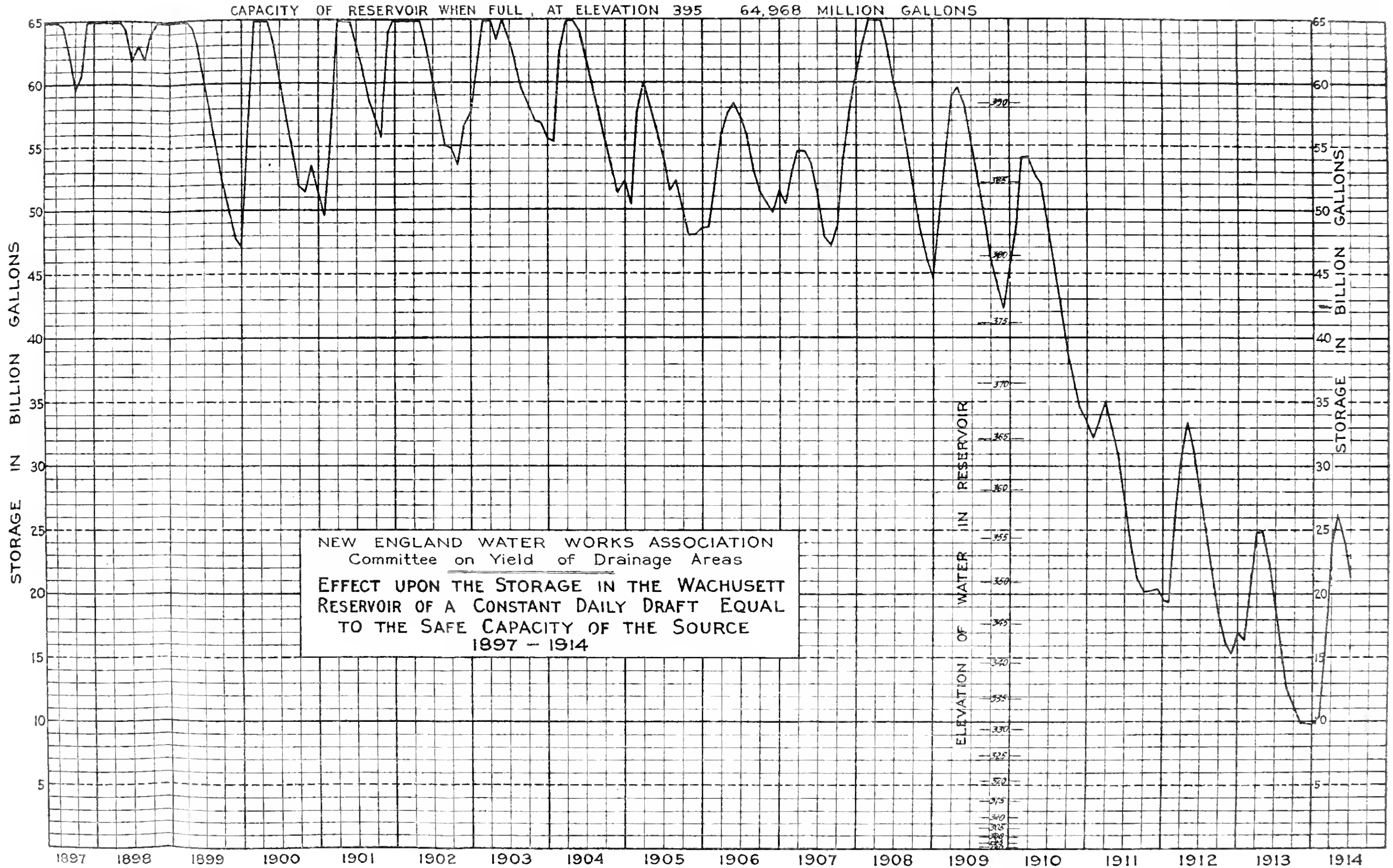
The accompanying diagram (Plate XII) shows graphically what the effect upon the Wachusett Reservoir would have been had it been filled in May, 1897, and had there been drawn from it a constant daily quantity of water which would have exhausted the available storage in January, 1914. The diagram shows that from 1897 to 1908, inclusive, the reservoir would have filled and overflowed in all but three years, and that during this period it would not have been drawn more than 15 ft. below the high water level, or to such an extent as to reduce the amount of stored water to less than 68 per cent. of the total available storage.

Beginning in June, 1908, however, the reservoir would have reached a lower point each successive year, as already stated, reaching the lowest point up to the present time in January, 1914.

ADVANTAGE OF LARGE STORAGE CAPACITY.

A storage reservoir which is very large in proportion to its drainage area has certain advantages to which further attention will be called. One of these is that it cannot be exhausted in one or two dry years, but, depending upon the amount of development, three, four, five, or six years may be required to exhaust it.

One may determine from the tables the safe capacity of a source with such a reservoir, but it does not follow that it will be necessary to obtain an additional supply at precisely the time when the water consumption reaches such capacity. The safe capacity is based upon the records of the driest period, and under more usual conditions of average or wet years the source would continue to furnish a quantity considerably in excess of the safe capacity, and fill each spring. After the reservoir had failed to fill for a year or


CAPACITY OF RESERVOIR WHEN FULL, AT ELEVATION 395 64,968 MILLION GALLONS
NEW ENGLAND WATER WORKS ASSOCIATION
Committee on Yield of Drainage Areas
EFFECT UPON THE STORAGE IN THE WACHUSETT RESERVOIR OF A CONSTANT DAILY DRAFT EQUAL TO THE SAFE CAPACITY OF THE SOURCE
1897 – 1914
STORAGE IN BILLION GALLONS
ELEVATION OF WATER IN RESERVOIR
65
60
55
50
45
40
35
30
25
20
15
10
5
390
385
380
375
370
365
360
355
350
345
340
335
330
325
320
315
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914

two, there might still be time before it could be exhausted to obtain an additional supply.

This distinction between a small storage capacity, sufficient to tide over, say, from four to six months when the flow of the streams is very low, and a large storage capacity, such as is above described, should be kept always in mind. The small storage reservoir would be drawn down to a considerable extent nearly every year, and its exhaustion in a very dry year would come without much warning. Under such circumstances, the safe capacity should be reckoned on a very conservative basis, unless it is feasible to obtain an emergency supply from some source without delay. With the larger storage reservoir there is more time available for obtaining an additional supply, so that the safe capacity, where it is possible to obtain such a supply without too much delay, may be reckoned on a less conservative basis.

A large storage reservoir is especially advantageous for sanitary reasons.

MINIMUM FLOW OF STREAMS.

As already stated, one item of information asked for from those in charge of stream gagings was the daily flow of streams during the driest periods of one, two, and three months included in the records. Such records are at times useful in determining the capacity of supplies taken from streams without any considerable amount of storage, and are also useful in connection with studies of water power. The results obtained from different drainage areas are necessarily variable.

Records of this kind have value only when deduced from drainage areas having small water surfaces, because the evaporation from large water surfaces in very dry periods frequently exceeds the yield of the drainage area, and estimates of the amount of evaporation during any short period are likely to be considerably in error.

It takes comparatively little storage to increase to a considerable extent the minimum flow of a stream, and in the tables which follow the records of run-off which have been corrected for water drawn from storage have been kept separate from the records of

TABLE 29. — TABLE GIVING MINIMUM FLOW OF DRAINAGE AREAS IN GALLONS DAILY PER SQUARE MILE OF LAND SURFACE, FOR PERIODS RANGING FROM ONE WEEK TO THREE MONTHS.

Correction Made for Water Drawn from Storage.

Drainage Area.			Period.				
Name.	Square Miles.	Year.	One Week.	Two Weeks.	One Month.	Two Months.	Three Months.
Holyoke, Manhan River	13.0	1900	51 000	56 000	78 000	123 000	127 000
Westfield, Tillotson Brook*	5.84	1910	130 000	137 000	144 000	176 000	180 000
Pawtucket, Abbott Run	26.19	1910	—	—	54 000	71 000	103 000
Waterbury, West Branch of Naugatuck River	17.80	1912	—	—	36 000	45 000	43 000
New York Water Works:							
Esopus Creek	239.0	1908	52 000	57 000	66 000	—	—
		1909	—	—	—	—	143 000
		1913	—	—	—	115 000	—
Rondout Creek	102.0	1908	38 000	61 000	79 000	95 000	—
		1909	—	—	—	—	136 000
Schoharie Creek	236.0	1908	19 000	20 000	31 000	63 000	—
		1909	—	—	—	—	77 000

TABLE 30. — TABLE GIVING MINIMUM FLOW OF DRAINAGE AREAS IN GALLONS DAILY PER SQUARE MILE, FOR PERIODS RANGING FROM ONE WEEK TO THREE MONTHS.

No Correction made for Water Drawn from Storage.

Drainage Area.			Period.				
Name.	Square Miles.	Year.	One Week.	Two Weeks.	One Month.	Two Months.	Three Months.
Connecticut River at Orford, N. H.	3 300	1908	95 000	101 000	118 000	143 000	151 000
Connecticut River at Sunderland, Mass.,	7 700	1908	128 000	135 000	143 000	150 000	160 000
Merrimack River at Lawrence, Mass.	4 452	1911	112 000	145 000	169 000	186 000	205 000

* See note on page 471.

the streams where the flow has been augmented to some extent by storage.

The records of the recent dry period do not necessarily include the driest months which have occurred, as there are sometimes some extremely dry months during years which, taken as a whole, are not extremely dry. For instance, the minimum flow of the Manhan River for periods of one, two, and three months occurred in July, August, and September, 1900, and not during the recent dry period.

Little dependence can be placed upon estimates of the safe capacity of small streams not supplemented with storage water.

SUMMARY.

1. Reason for Report. The committee was appointed early in 1911 on account of the low flow of the streams during the years 1908, 1909, and 1910. The year 1911 proved to be even drier than the preceding years, and 1912 and 1913 nearly as dry.

2. Recent Dry Period the Driest since Streams have been Measured. Until the recent dry period, that from 1879 to 1884 was the driest on record. The recent period has been drier in the greater part of New England, but not as dry in eastern New York. Judging from rainfall records, still drier periods occurred prior to 1850.

3. Yield of Drainage Areas Defined. In the case of a drainage area on which there are no storage reservoirs or ponds, the yield of a drainage area means the quantity of water flowing in the stream at the lower end of the area.

When a storage reservoir has been built upon the stream and the discharge is measured at the dam, the yield of a drainage area, as water works records are usually kept, means the quantity of water discharged at the dam, corrected by adding or subtracting, respectively, the quantity of water drawn from or added to storage. It is therefore approximately the natural flow of the stream, but not exactly, because there is a loss of water by evaporation from the surface of the reservoir, which is not measured.

In the case of rivers like the Merrimack and Connecticut, where it is not feasible to make corrections for the amount of water

drawn from or added to storage, the yield of a drainage area, as usually recorded, does not mean the natural flow of the stream, but the natural flow increased by water drawn from storage in the dry season and decreased by the water added to storage when the reservoirs are filling.

When there is a reservoir at the lower end of a drainage area, there is sometimes added an unmeasured loss due to leakage past the dam, and there may be storage of which no account is taken, as, for instance, that in the interstices of the ground around the reservoirs and in small reservoirs not under water works control.

4. Evaporation from Water Surfaces Important. When there are large water surfaces the evaporation is an important item, and the yield of one drainage area should not be deduced from that of another without taking account of this element.

5. Yield of Water Surfaces. The yield of a water surface is the difference between the precipitation upon and the evaporation from such surface, multiplied by its area. In the summer, when the evaporation is high, the evaporation is nearly always greater than the precipitation, while in the cold weather the reverse is true.

6. Yield of Land Surfaces. The measurements of the yield of a drainage area necessarily include the combined yield of land and water surfaces, but it is feasible to estimate the yield of water surfaces with a fair degree of accuracy, and when such yield is deducted from the total yield of a drainage area, the remainder is the yield of the land surface. A much better comparison of the yield of different drainage areas can be made when the yield of land surfaces only is used.

7. Swamps. Swamps are generally covered with water during a part of the year and are damp at other times, so that as regards evaporation they are intermediate between water surfaces and ordinary land surfaces. It has been assumed, for the purposes of this report, that 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps should be classed as water surface, and the remainder as land surface.

8. Relation of Precipitation to Yield. The water flowing from a drainage area has its origin, under nearly all circumstances, in the precipitation upon the area, and that part of the precipitation which is not evaporated, except for the small quantity of water absorbed by vegetation, finds its way into the streams. The precipitation in this section of the country is reasonably uniform throughout the year, but the evaporation which increases with the temperature varies greatly, being about six times as much in midsummer as in winter. Hence, a very much larger part of the precipitation is lost by evaporation from land surfaces in the warm than in the cold months. During the four years, 1908–1911, the percentage of the precipitation not evaporated, and consequently finding its way into the streams, was as follows:

	Per Cent.
December to April, inclusive	70.3
May, June, and November	46.0
July to October, inclusive	15.9

In years when the precipitation is large the percentage running off is greater than in years when it is small, because the evaporation from land surfaces does not increase at the same rate as the precipitation. As a result of many comparisons it was found that when the precipitation increased from 39.29 to 56.29 in. annually the percentage running off increased from 43.1 to 53.3. To express the relation in another way, 77 per cent. of the above increase in precipitation was represented by the run-off in the streams.

The above figures are based on the maximum and minimum precipitation on several drainage areas during a long series of years. If comparisons were to be made between the low and high precipitation during a series of comparatively dry years, as, for instance, between annual precipitations of 35 and 40 in., or 40 and 45 in., less than 77 per cent. of the difference in precipitation would be represented by the run-off. It has been assumed somewhat arbitrarily that in these cases the percentages would be, respectively, 65 and 70.

9. Elevation of Drainage Area an Important Factor. Other things being equal, the precipitation and consequently the

yield of a drainage area increases with the elevation above the sea. The lowest records of yield received are those of low-lying drainage areas near the coast, and the highest yield recorded is of drainage areas at a high elevation in the Catskill Mountains. Observations on the top of Mt. Washington from 1876 to 1886 gave an average precipitation of 90.13 in., while the averages for the Sudbury and Cochituate watersheds for the same period were, respectively, 44.02 and 42.59 in.

10. Capacity Tables and Diagrams. The principal aim of the report is to furnish tables and diagrams based upon trustworthy information to facilitate computations of the safe capacity of sources of water supply. In order to use these tables, it is necessary to have:

1. The drainage area in square miles.
2. The area of water surfaces when the reservoirs are full, in square miles.
3. The *available* capacity of the storage reservoir, in million gallons.

In computing the tables, the area of water surfaces in most instances included 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps, and in applying the tables in such cases it is desirable that the area of water surfaces should include these percentages of the swamps on the drainage areas under consideration, if the most accurate results are desired.

The tables give results which vary widely, but they show what the safe capacity of proposed sources would be on the basis of the conditions which actually existed upon the drainage areas upon which the tables were based. With such wide differences in results, good judgment and a complete knowledge of the facts upon which the tables are based are necessary in order to determine intelligently the probable safe capacity of any given source.

11. Minimum Flow of Streams. Tables on page 466 give the minimum flow of streams for short periods of from one week to three months. The results vary widely and indicate that one

should be very conservative in fixing the safe capacity of a source where there is little or no storage capacity.

Respectfully presented,

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Committee.

NOTE: Since writing the above report a very low stream flow occurred in some parts of New England in the autumn of 1914. The minimum flow of Tillotson Brook, Westfield, during this time has been much lower than the previous results recorded in the table on page 442, thus confirming the views expressed in the last of the above paragraphs as to the necessity of being conservative in fixing the safe capacity of a source where there is little or no storage capacity.

The new Tillotson Brook records are as follows:

	Gals. Daily per Sq. Mile.
One week, September 18–24, 1914	86 000
Two weeks, September 11–24, 1914	94 000
One month, September, 1914	111 000
Two months, August–September, 1914	140 000
Three months, August, September, October, 1914	152 000

Appendix No. 1.

DETAILED STATISTICS OF THE YIELD OF DRAINAGE AREAS.

Maine.
- Sebago Lake.

New Hampshire.
- Connecticut River at Orford.

Massachusetts.
- Connecticut River at Sunderland.
- Deerfield River at Shelburne Falls.
- Merrimack River at Lawrence.
- Cambridge Water Works, Stony Brook.
- Holyoke Water Works, Manhan River.
- Metropolitan Water Works:
  - Wachusett Reservoir.
  - Sudbury River.
  - Lake Cochituate.
- Springfield Water Works, Westfield Little River.
- Westfield Water Works, Tillotson Brook.
- Worcester Water Works, Tatnuck Brook.

Rhode Island.
- Pawtucket Water Works, Abbott Run.

Connecticut.
- Hartford Water Works, Hartford Reservoirs.
- Norwich Water Works, Fairview and Meadow brooks.
- Waterbury Water Works, West Branch of Naugatuck River.

New York.
- New York Water Works:
  - Croton River.
  - Esopus Creek.
  - Rondout Creek.
  - Schoharie Creek

SEBAGO LAKE, MAINE.

Information furnished by S. D. Warren Co.
Yield measured at the outlet of lake, 1908–1911.

Drainage area, including water surfaces	436.0 sq. miles
Area of water surfaces	71.6 sq. miles
Area of land surface	364.4 sq. miles

The area of Sebago Lake is 45.6 sq. miles, and of thirty-eight other lakes and ponds 24.4 sq. miles.

Estimated area of undrained swamps, 4 sq. miles.

Correction was made for the effect of storage in Sebago Lake in all years and in the years 1909, 1910, and 1911, a further correction was made for the effect of storage in other lakes, but gage heights were taken only in one additional lake, so that the corrections for storage are uncertain.

The water from Sebago Lake is used for supplying the Portland water district, and due account has been taken of the water so used and of leakage at the outlet of the lake.

The whole drainage area is mountainous and hilly and the soil is gravelly and sandy; about 80 per cent. of the whole area is forested.

The elevation of Sebago Lake is 262 ft. above sea level. Most of the flow is measured through turbines which were tested at the Holyoke Testing Flume and again after installation, the quantity discharged in the latter test being carefully measured by current meters. The results of the tests differed 2 per cent.

The gagings do not conform with others as to the distribution of flow among the different months of the year, which appears to be due to the incompleteness of the records of the gain or loss of storage at some of the large lakes. The main value of the gagings, therefore, lies in results for a year or series of years and not for shorter periods.

The rain gages used are Standard United States rain gages located near the ground.

SEBAGO LAKE, MAINE, 1908.

Yield of lake at outlet. Total drainage area, 436 sq. miles. Area of land surface, 364.4 sq. miles.

Month	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected. Land Surface.		Precipitation Collected. Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	12 704	2 125	14 829	1.125	1.74	1.099	1.70	2.66	2.007	75.4	1.959	73.7
Feb.	12 135	3 912	16 047	1.148	1.78	1.273	1.97	4.19	1.915	45.7	2.124	50.8
Mar.	14 648	560	15 208	1.297	2.01	1.127	1.74	2.15	2.312	107.6	2.009	93.4
Apr.	25 316	324	25 640	2.316	3.58	1.961	3.03	2.53	3.999	158.0	3.393	134.1
May	18 047	2 986	21 033	1.598	2.47	1.560	2.41	5.00	2.843	56.9	2.785	55.4
June	14 987	−3 148	11 839	1.371	2.12	0.906	1.40	0.77	2.366	307.3	1.569	203.9
July	3 109	−1 953	1 156	0.275	0.43	0.086	0.13	3.43	0.491	14.3	0.153	4.5
Aug.	10 710	−2 488	8 222	0.948	1.47	0.609	0.94	3.20	1.692	52.9	1.085	33.9
Sept.	1 225	−3 061	−1 836	0.112	0.17	−0.143	−0.22	0.86	0.193	22.4	−0.243	−28.3
Oct.	1 760	1 595	3 355	0.156	0.24	0.249	0.38	3.58	0.278	7.8	0.444	12.4
Nov.	2 122	162	2 284	0.194	0.30	0.173	0.27	1.43	0.335	23.4	0.302	21.1
Dec.	4 634	3 185	7 819	0.410	0.63	0.581	0.90	3.44	0.732	21.3	1.034	30.1
Year	121 397	4 199	125 596	0.912	1.41	0.790	1.22	33.24	19.163	57.6	16.614	49.9

SEBAGO LAKE, MAINE, 1909.

Jan.	2 489	5 853	8 342	0.220	0.34	0.617	0.95	5.66	0.392	6.9	1.101	19.5
Feb.	9 151	5 435	14 586	0.897	1.39	1.197	1.85	5.42	1.445	26.7	1.927	35.6
Mar.	21 133	2 613	23 746	1.871	2.89	1.759	2.72	3.80	3.337	87.8	3.140	82.6
Apr.	59 348	1 630	60 978	5.429	8.40	4.669	7.22	3.70	9.371	253.3	8.071	218.1
May	20 316	871	21 187	1.798	2.78	1.570	2.43	3.30	3.208	97.0	2.801	85.0
June	11 875	−1 170	10 705	1.086	1.68	0.819	1.27	2.36	1.875	79.4	1.419	60.1
July	5 998	−3 148	2 850	0.531	0.82	0.210	0.33	2.47	0.947	38.3	0.374	15.1
Aug.	5 376	−4 242	1 134	0.475	0.74	0.085	0.13	1.79	0.848	47.4	0.150	8.4
Sept.	7 911	−2 613	5 301	0.723	1.12	0.404	0.63	5.42	1.250	23.1	0.702	13.0
Oct.	3 139	−1 219	1 920	0.278	0.43	0.143	0.22	1.32	0.496	37.6	0.254	19.2
Nov.	−1 310	1 605	295	−0.120	−0.19	0.021	0.03	2.59	−0.207	−8.0	0.039	1.5
Dec.	−1 160	2 551	1 391	−0.103	−0.16	0.102	0.16	2.93	−0.183	−6.2	0.184	6.3
Year	144 269	8 166	152 435	1.084	1.68	0.966	1.50	40.76	22.779	55.9	20.162	49.5

SEBAGO LAKE, MAINE, 1910.

Jan.	8 495	3 150	11 645	0.752	1.16	0.862	1.33	3.49	1.341	38.4	1.538	44.1
Feb.	3 514	4 449	7 963	0.344	0.53	0.652	1.01	4.63	0.555	12.0	1.049	22.7
Mar.	29 488	−88	29 400	2.610	4.04	2.179	3.37	1.63	4.654	285.5	3.889	238.3
Apr.	29 843	2 613	32 456	2.730	4.22	2.485	3.84	4.49	4.714	105.0	4.299	95.8
May	16 853	−659	16 194	1.492	2.31	1.200	1.86	2.07	2.662	128.5	2.141	103.5
June	11 147	−75	11 072	1.020	1.57	0.847	1.31	3.24	1.760	54.3	1.467	45.3
July	3 393	−4 065	−672	0.300	0.46	−0.050	−0.08	1.80	0.536	29.8	−0.089	−4.9
Aug.	5 750	−1 070	4 680	0.509	0.79	0.347	0.54	4.34	0.908	20.9	0.619	14.3
Sept.	3 737	−162	3 575	0.342	0.53	0.272	0.42	3.19	0.590	18.5	0.473	14.8
Oct.	−822	−25	−847	0.073	0.11	−0.063	−0.10	2.28	−0.130	−5.7	−0.112	−4.9
Nov.	−2 816	1 244	−1 572	−0.258	−0.40	−0.121	−0.19	2.30	−0.445	−19.4	−0.208	−9.0
Dec.	−2 175	3 173	998	−0.193	−0.30	0.075	0.12	3.43	−0.344	−10.0	0.132	3.8
Year	106 407	8 485	114 892	0.810	1.25	0.724	1.12	36.89	16.801	45.6	15.198	41.2

SEBAGO LAKE, MAINE, 1911.

Jan.	2 548	2 031	4 579	0.226	0.35	0.339	0.52	2.59	0.402	15.5	0.605	23.4
Feb.	5 564	2 699	8 263	0.545	0.84	0.678	1.05	3.22	0.879	27.3	1.091	33.9
Mar.	5 257	3 733	8 990	0.465	0.72	0.666	1.03	4.70	0.830	17.7	1.189	25.3
Apr.	39 805	−1 157	38 648	3.641	5.63	2.958	4.57	1.46	6.283	430.5	5.113	350.0
May	12 565	−1 925	10 640	1.112	1.72	0.788	1.22	1.05	1.985	189.0	1.406	133.9
June	11 018	−348	10 670	1.008	1.56	0.509	0.79	3.02	1.739	57.6	1.413	46.8
July	2 480	−523	1 957	0.220	0.32	0.145	0.22	4.58	0.392	8.6	0.259	5.7
Aug.	3 681	−3 061	620	0.326	0.50	0.046	0.07	2.74	0.582	21.2	0.082	3.0
Sept.	857	859	1 716	0.078	0.12	0.131	0.20	4.01	0.135	3.4	0.227	5.7
Oct.	2 925	75	3 000	0.259	0.40	0.222	0.34	2.36	0.462	19.5	0.397	16.8
Nov.	2 373	2 837	5 210	0.217	0.34	0.399	0.62	3.58	0.375	10.5	0.691	19.3
Dec.	−3 155	3 419	264	−0.279	−0.43	0.019	0.03	3.63	−0.498	−13.7	0.035	1.0
Year	85 918	8 639	94 557	0.652	1.01	0.575	0.89	36.94	13.566	36.7	12.508	33.9

CONNECTICUT RIVER AT ORFORD, N. H.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces	3 300 sq. miles
Estimated area of water surfaces	20 sq. miles
Area of land surface	3 280 sq. miles

Area of swamps, unknown.

No correction is made for evaporation or storage.

The drainage area located in New Hampshire and Vermont has generally steep slopes, which are for the most part forested, although there are considerable areas under cultivation. A considerable portion of the White Mountain district in New Hampshire is included, as well as the eastern slopes of the Green Mountains in Vermont.

The elevation above the sea ranges from 380 to 6 279 ft.

The discharge is based upon measurements of the elevation of the surface of the water in the river, usually taken daily, and the use of a rating curve based upon occasional current meter measurements. The discharge during the frozen season is affected by ice, which changes the relation of the gaging heights to the discharge. The monthly discharge during low water periods is probably subject to errors of from 5 to 10 per cent., and during the frozen season may occasionally be in error 15 to 25 per cent.

Although it cannot be claimed that the gagings are sufficiently exact to be wholly trustworthy, they are given in connection with other measurements of the Connecticut River and of the Deerfield River as an indication of the larger yield of drainage areas having a high elevation.

The precipitation upon this drainage area is deduced from United States Weather Bureau records at the following stations: Bloomfield, Vt.; St. Johnsbury, Vt.; Chelsea, Vt.; Bethlehem, N. H.

The mean precipitation deduced from these records is probably considerably too low, as none of the stations are located in the regions of high elevation, where the precipitation is the greatest. This probably accounts in part for the high percentage of rainfall running off, as given in the tables.

CONNECTICUT RIVER AT ORFORD, N. H., 1908.

Total drainage area, 3 300 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area Inches.	Precipitation Collected.	
	Cu. Ft. per. Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	4 410	0.87	1.34	1.80	1.55	86.2
February	4 830	0.94	1.46	3.08	1.57	51.0
March	7 580	1.49	2.30	1.97	2.66	135.0
April	12 800	2.51	3.88	2.38	4.33	182.0
May	12 700	2.49	3.85	3.39	4.44	131.0
June	4 450	0.87	1.35	3.51	1.51	43.0
July	1 540	0.30	0.47	3.28	0.54	16.5
August	1 690	0.33	0.51	4.05	0.59	14.6
September	627	0.12	0.19	0.97	0.21	21.6
October	747	0.15	0.23	1.76	0.26	14.8
November	1 040	0.21	0.32	1.55	0.35	22.6
December	1 200	0.23	0.36	2.54	0.42	16.5
The Year	4 470	0.88	1.36	30.28	18.43	60.8

CONNECTICUT RIVER AT ORFORD, N. H., 1909.

January	2 690	0.53	0.82	4.07	0.94	23.1
February	4 000	0.78	1.21	3.71	1.26	34.0
March	3 620	0.71	1.10	1.70	1.27	74.7
April	25 400	4.98	7.70	3.51	8.60	245.0
May	14 400	2.82	4.36	4.18	5.03	120.0
June	3 890	0.76	1.18	2.97	1.32	44.4
July	1 490	0.29	0.45	2.82	0.52	18.4
August	836	0.16	0.25	2.68	0.29	10.8
September	1 460	0.28	0.44	5.12	0.49	9.6
October	2 360	0.47	0.72	1.25	0.82	65.5
November	2 380	0.47	0.72	2.07	0.80	38.6
December	2 070	0.41	0.63	1.12	0.72	64.3
The Year	5 370	1.05	1.63	35.20	22.06	62.6

CONNECTICUT RIVER AT ORFORD, N. H., 1910.

January	3 130	0.61	0.95	2.85	1.09	38.2
February	2 000	0.39	0.61	3.49	0.63	18.0
March	12 800	2.51	3.88	1.26	4.47	355.0
April	14 500	2.84	4.39	3.18	4.90	154.0
May	9 080	1.78	2.75	4.60	3.17	68.9
June	6 050	1.18	1.83	3.52	2.04	57.9
July	1 630	0.32	0.49	3.45	0.57	16.5
August	2 430	0.48	0.74	4.23	0.85	20.1
September	1 740	0.34	0.53	4.24	0.59	13.9
October	2 040	0.40	0.62	1.68	0.71	42.2
November	2 510	0.49	0.76	1.98	0.85	42.9
December	1 520	0.30	0.46	2.13	0.53	24.9
The Year	4 960	0.97	1.50	36.61	20.40	55.7

CONNECTICUT RIVER AT ORFORD, N. H., 1911.

January	2 520	0.49	0.76	1.74	0.88	50.6
February	1 360	0.26	0.41	1.92	0.43	22.4
March	2 450	0.48	0.74	3.05	0.86	28.2
April	16 800	3.29	5.09	1.00	5.68	568.0
May	11 300	2.21	3.42	0.92	3.94	428.0
June	2 440	0.48	0.74	3.11	0.82	26.4
July	1 180	0.23	0.36	4.58	0.41	9.0
August	1 620	0.32	0.49	5.57	0.57	10.2
September	2 360	0.47	0.72	3.84	0.80	20.8
October	4 310	0.85	1.31	3.50	1.51	43.1
November	4 340	0.85	1.32	2.28	1.47	64.5
December	8 250	1.62	2.50	2.91	2.88	99.0
The Year	4 930	1.00	1.49	34.42	20.25	58.8

CONNECTICUT RIVER AT SUNDERLAND, MASS.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces	7 700 sq. miles
Estimated area of water surfaces	60 sq. miles
Area of land surface	7 640 sq. miles

Area of swamps, unknown.

No correction has been made for evaporation or storage.

The drainage area located in Massachusetts, New Hampshire, and Vermont has generally steep slopes, which are for the most part forested, although there are considerable areas under cultivation. A considerable portion of the White Mountain district in New Hampshire is included, as well as the easterly slopes of the Green Mountains in Vermont.

The Deerfield River, a large tributary in southern Vermont and western Massachusetts, is an especially quick spilling stream, with steep slopes and narrow valleys. In southern New Hampshire and a part of Massachusetts the country is flatter, with a considerable number of ponds and reservoirs.

The prevailing surface material is glacial drift.

The elevation above the sea varies from 100 ft. at Sunderland to 6 279 ft. at the top of Mt. Washington. The upper portion of the Deerfield River drainage area reaches an elevation of 3 800 ft.

The discharge is based upon measurements of the elevation of the surface of the water in the river taken twice daily and the use of a rating curve based on occasional current meter measurements. The discharge during the frozen season is affected by ice, which changes the relation of the gage height to the discharge. The figures of monthly discharge during low water periods are probably subject to errors of from 5 to 10 per cent. During the frozen season they may occasionally be in error 15 to 25 per cent.

Although the gagings are not wholly trustworthy, they are given for the reasons already stated in connection with gagings of the river at Orford, N. H.

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1908

Total drainage area, 7 700 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent
January	13 500	1.55	1.75	2.14	2.02	94.3
February	15 200	1.27	1.97	3.63	2.12	58.4
March	24 700	2.07	3.21	2.02	3.70	183.0
April	32 600	2.73	4.23	2.70	4.72	175.0
May	32 200	2.70	4.18	4.46	4.83	109.0
June	10 300	0.87	1.34	2.11	1.50	71.0
July	3 770	0.32	0.49	3.81	0.56	14.7
August	4 690	0.39	0.61	4.45	0.70	15.7
September	2 010	0.17	0.26	0.91	0.29	31.9
October	2 000	0.17	0.26	1.77	0.30	17.0
November	2 210	0.18	0.29	1.11	0.32	28.8
December	3 710	0.31	0.48	2.49	0.56	22.5
The Year	12 200	1.03	1.59	31.60	21.62	68.4

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1909.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent
January	5 980	0.50	0.78	3.22	0.90	27.9
February	12 000	1.01	1.56	4.30	1.63	37.9
March	14 700	1.23	1.91	2.29	2.20	96.0
April	56 400	4.73	7.32	3.36	8.17	243.0
May	28 400	2.39	3.69	3.45	4.26	123.0
June	10 600	0.89	1.38	3.25	1.54	47.4
July	3 250	0.27	0.42	3.20	0.49	15.3
August	2 900	0.25	0.38	3.31	0.44	13.3
September	2 550	0.21	0.33	4.66	0.37	7.9
October	4 420	0.37	0.57	1.54	0.66	42.8
November	3 970	0.34	0.52	2.09	0.58	27.7
December	4 520	0.38	0.59	1.99	0.68	34.1
The Year	12 400	1.05	1.62	36.66	21.92	59.7

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1910.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent
January	13 000	1.09	1.69	3.75	1.95	52.0
February	8 340	0.70	1.08	3.85	1.12	29.1
March	41 600	3.49	5.40	1.14	6.23	545.0
April	30 000	2.52	3.90	2.84	4.35	153.0
May	17 500	1.47	2.27	3.55	2.62	73.8
June	14 600	1.23	1.90	3.18	2.12	66.8
July	3 260	0.27	0.42	2.41	0.49	20.3
August	4 200	0.35	0.54	3.29	0.63	19.1
September	3 100	0.26	0.40	4.00	0.45	11.2
October	3 350	0.28	0.44	1.36	0.50	36.8
November	4 950	0.41	0.64	2.73	0.72	26.4
December	2 810	0.23	0.36	2.00	0.42	21.0
The Year	12 200	1.03	1.59	34.10	21.60	63.4

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1911.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent
January	10 000	0.84	1.30	2.09	1.50	71.7
February	4 200	0.36	0.55	2.33	0.57	24.5
March	8 960	0.75	1.16	3.42	1.34	39.2
April	36 400	3.06	4.73	1.24	5.28	426.0
May	19 600	1.65	2.55	1.33	2.94	221.0
June	6 060	0.51	0.79	3.05	0.88	28.8
July	2 260	0.19	0.29	4.19	0.34	8.1
August	2 860	0.24	0.37	4.43	0.43	9.7
September	5 470	0.46	0.71	3.95	0.79	20.0
October	16 300	1.37	2.12	5.31	2.44	46.0
November	12 600	1.06	1.64	2.59	1.83	70.6
December	18 000	1.51	2.34	2.87	2.70	94.0
The Year	11 900	1.00	1.55	36.80	21.04	57.7

The precipitation upon this drainage area is deduced from United States Weather Bureau records at the following stations: Bloomfield, Vt.; St. Johnsbury, Vt.; Chelsea, Vt.; Bethlehem, N. H.; Grafton, N. H.; Alstead, N. H.; Cavendish, Vt.; Woodstock, Vt.; Jacksonville, Vt.; Keene, N. H.; Fitchburg, Mass.; Turners Falls, Mass.

The mean precipitation deduced from these records is probably considerably too low, as none of the stations are located in the regions of high elevation, where the precipitation is the greatest. This probably accounts in part for the high percentage of rainfall running off, as given in the tables.

DEERFIELD RIVER AT SHELBURNE FALLS, MASS.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces . . .	501 sq. miles
Estimated area of water surfaces	1 sq. mile
Area of land surface.	500 sq. miles

Area of swamps, very small.

No correction is made for evaporation or storage.

The drainage area consists of steep slopes and narrow valleys, nearly all forested and with practically no storage. Its elevation ranges from 260 to 3 800 ft. above sea level and averages about 1 800 ft.

The surface material is glacial drift, most of it unmodified, with the steeper slopes of ledge and bowlders.

The discharge is measured at the plant of the Greenfield Electric Light and Power Company below Shelburne Falls. The results are based upon three daily readings of the heights of water at the dam and hourly readings of wheel gate openings and head. Low water estimates of monthly discharge are fairly good, as at such times practically all water is used by the wheels. At medium and high water, estimates are fairly good except at occasional intervals when the flashboards on the dam are temporarily displaced.

The United States Weather Bureau records of precipitation

at Jacksonville, Vt. (elevation about 1 400 ft.) are used for the period January, 1908, to November, 1911, inclusive, except where records are omitted, in which case Manchester, Vt., is used. Beginning with December, 1911, the Weather Bureau records at Somerset, Vt. (elevation 2 096 ft.), are used. The precipitation at Jacksonville is undoubtedly less than the average precipitation in the Deerfield basin above Shelburne Falls, owing to the higher average elevation of the basin.

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1908.
Total drainage area, 501 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	731	0.94	1.46	3.86	1.68	43.5
February	965	1.25	1.93	4.09	2.08	50.9
March	2 210	2.86	4.42	1.20	5.08	423.0
April	2 550	3.28	5.09	2.57	5.68	221.0
May	2 700	3.48	5.39	3.43	6.21	181.0
June	620	0.80	1.24	1.84	1.38	75.0
July	370	0.48	0.74	4.61	0.85	18.4
August	274	0.36	0.55	3.33	0.63	18.9
September	85	0.11	0.17	0.83	0.19	22.9
October	115	0.15	0.23	2.20	0.27	12.2
November	207	0.26	0.41	0.96	0.46	48.0
December	236	0.30	0.47	2.46	0.54	21.9
The Year	922	1.19	1.84	31.38	25.05	79.9

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1909.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.
January	730	0.94	1.46	4.40	1.68	38.2
February	1 230	1.59	2.46	4.47	2.56	57.2
March	904	1.16	1.80	1.67	2.08	125.0
April	5 060	6.52	10.1	2.63	11.27	428.0
May	1 350	1.74	2.70	4.47	3.10	69.3
June	689	0.89	1.38	2.85	1.54	54.0
July	152	0.19	0.30	1.68	0.35	20.8
August	249	0.32	0.50	3.90	0.57	14.6
September	313	0.40	0.62	5.45	0.70	12.8
October	314	0.41	0.63	4.95	0.72	14.5
November	284	0.37	0.57	2.39	0.63	26.3
December	242	0.31	0.48	0.88	0.56	63.5
The Year	960	1.24	1.92	39.74	25.76	64.8

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1910.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.
January	1 500	1.93	2.99	3.07	3.45	112.0
February	970	1.25	1.94	2.99	2.02	67.0
March	3 630	4.68	7.25	1.43	8.35	583.9
April	1 850	2.38	3.69	2.16	4.12	190.0
May	851	1.10	1.70	4.51	1.96	43.5
June	1 124	1.45	2.24	2.81	2.50	89.0
July	163	0.21	0.33	2.65	0.38	14.3
August	110	0.14	0.22	2.00	0.25	12.5
September	163	0.21	0.33	4.92	0.37	7.5
October	132	0.17	0.26	0.89	0.30	33.7
November	307	0.39	0.61	3.44	0.68	19.8
December	169	0.22	0.34	0.38	0.61	160.0
The Year	914	1.19	1.84	31.25	24.99	79.6

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1911.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	997	1.28	1.99	4.04	2.29	56.8
February	301	0.39	0.60	5.06	0.62	12.2
March	947	1.22	1.89	4.57	2.18	47.6
April	3 230	4.17	6.46	2.24	7.21	322.0
May	986	1.27	1.97	2.06	2.27	110.0
June	774	1.00	1.55	4.94	1.73	35.0
July	148	0.19	0.30	1.21	0.34	28.1
August	234	0.30	0.47	2.00	0.54	27.0
September	668	0.86	1.33	5.20	1.49	28.7
October	2 130	2.75	4.26	10.98	4.91	44.8
November	1 180	1.52	2.36	1.81	2.63	145.0
December	1 100	1.42	2.19	4.04	2.52	62.4
The Year	1 060	1.36	2.11	48.15	28.73	59.7

MERRIMACK RIVER AT LAWRENCE, MASS.

Information furnished by R. A. Hale, Principal Assistant Engineer of the Essex Company, Lawrence, Mass.

Yield measured by engineers of Essex Company, 1908–1912.

Drainage area, including water surfaces . . . 4 452 sq. miles

The area of water surfaces has not been carefully estimated, but there are included in the drainage area Lake Winnipiseogee (72 sq. miles), Squam Lake (14 sq. miles), and a great many smaller lakes, which, according to a rough estimate, aggregate about 97 sq. miles, making the total area of water surface included in lakes and ponds 183 sq. miles. The mill ponds and water surfaces of the river from the dam at Lawrence to Franklin, N. H., including some of the larger tributaries, would make an additional water surface of about 17 sq. miles, making a total area of water surface of about 200 sq. miles. According to this estimate the water surfaces represent 4.5 per cent. of the whole drainage area.

The area of swamps is unknown, but as part of the area is rather flat, the area of swamps is considerable. Owing to the large area of lakes, ponds, and reservoirs, the summer flow is materially augmented by the water drawn from them, but it has not been practicable to make corrections for storage or evaporation, and the discharge given is the flow of the stream at Lawrence.

The drainage area as above given does not include 212 sq. miles of the original drainage area, which has been appropriated for the water supply of the Metropolitan Water District, and the gagings at Lawrence are corrected for the water which flows past the Metropolitan Water Works dams.

The greater part of the drainage area lies at rather a low elevation. The river at Lawrence is about 40 ft. above sea level. Lake Winnipiseogee, which is far toward the upper end of the drainage area, is 500 ft. above sea level. At the extreme head waters, however, in the Pemigewasset valley, the Franconia Mountains rise to a maximum elevation of 5 260 ft. The mean elevation of the drainage area probably is between 500 and 700 ft.

The precipitation is an average of that recorded at 34 rainfall stations located in different parts of the drainage area or a short distance outside of it. In making the average, however, five stations on the Wachusett drainage area and five upon the Sudbury and Cochituate drainage areas are averaged and each treated as one station in making the general average.

The rain gages are generally located in the valleys, and their average elevation is much less than the average elevation of the drainage area. It is, therefore, probable that the actual precipitation upon the drainage area is larger than that recorded in the tables.

MERRIMACK RIVER AT LAWRENCE, MASS., 1908.

Total drainage area, 4 452 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	8 665	1.258	1.946	2.69	2.244	83.4
February	7 335	1.063	1.648	4.17	1.777	42.6
March	11 125	1.612	2.499	2.44	2.881	118.1
April	11 808	1.712	2.652	2.05	2.959	144.3
May	11 440	1.660	2.570	4.65	2.964	63.7
June	4 148	0.602	0.932	1.02	1.040	102.0
July	2 322	0.337	0.522	3.86	0.602	15.6
August	2 972	0.431	0.668	4.93	0.770	15.6
September	1 686	0.245	0.379	0.88	0.423	48.1
October	1 467	0.213	0.330	2.21	0.381	17.2
November	1 575	0.228	0.354	1.06	0.395	37.3
December	1 870	0.271	0.420	2.86	0.484	16.9
The Year	5 534	0.804	1.243	32.82	16.920	51.6

MERRIMACK RIVER AT LAWRENCE, MASS., 1909.

Month.	Yield of Drainage Area. Cu. Ft. per Sec.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	3 014	0.437	0.677	3.87	0.781	20.2
February	6 957	1.010	1.563	4.84	1.626	33.6
March	7 545	1.095	1.695	3.27	1.955	59.8
April	15 156	2.199	3.404	4.05	3.799	93.8
May	8 687	1.260	1.951	2.44	2.250	92.2
June	4 221	0.612	0.948	2.73	1.058	38.8
July	1 992	0.289	0.447	2.42	0.515	21.3
August	1 675	0.243	0.376	2.79	0.434	15.6
September	1 645	0.238	0.369	4.36	0.412	9.4
October	1 878	0.273	0.422	1.24	0.487	39.3
November	1 726	0.250	0.388	2.45	0.433	17.7
December	2 242	0.325	0.504	3.17	0.581	18.3
The Year	4 728	0.686	1.062	37.63	14.331	38.1

MERRIMACK RIVER AT LAWRENCE, MASS., 1910.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	4 642	0.675	1.043	4.20	1.203	28.6
February	4 332	0.628	0.973	4.28	1.012	23.6
March	16 075	2.330	3.611	1.22	4.164	341.3
April	10 885	1.580	2.445	2.95	2.729	92.5
May	6 719	0.974	1.509	2.12	1.740	82.1
June	4 795	0.695	1.077	3.70	1.202	32.5
July	1 773	0.257	0.398	2.00	0.459	23.0
August	2 037	0.296	0.458	3.07	0.528	17.2
September	1 766	0.256	0.397	3.12	0.443	14.2
October	1 335	0.194	0.300	1.43	0.346	24.2
November	2 035	0.295	0.457	3.04	0.510	16.8
December	1 490	0.216	0.335	2.30	0.386	16.8
The Year	4 824	0.700	1.084	33.43	14.722	44.0

MERRIMACK RIVER AT LAWRENCE, MASS., 1911.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	2 778	0.403	0.624	2.28	0.720	31.6
February	2 147	0.311	0.482	2.55	0.501	19.6
March	5 554	0.805	1.248	3.46	1.439	41.6
April	13 557	1.968	3.045	1.66	3.398	204.7
May	6 055	0.878	1.360	1.22	1.568	128.5
June	2 455	0.356	0.551	2.63	0.615	23.4
July	1 184	0.172	0.266	3.99	0.307	7.7
August	1 461	0.212	0.328	4.50	0.378	8.4
September	1 937	0.281	0.435	3.34	0.485	14.5
October	4 089	0.593	0.918	4.03	1.059	26.3
November	4 668	0.677	1.049	3.49	1.171	33.6
December	5 718	0.830	1.284	3.04	1.481	48.7
The Year	4 300	0.624	0.966	36.19	13.122	36.3

MERRIMACK RIVER AT LAWRENCE, MASS., 1912.

Month.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	3 572	0.518	0.802	...	....	...
February	3 145	0.456	0.706	...	..	..
March	12 346	1.791	2.773		.	..

CAMBRIDGE, MASS., WATER WORKS.

Stony Brook.

Information furnished by L. M. Hastings, city engineer.

The yield of Stony Brook is measured at the Stony Brook dam in Waltham, 1908–February, 1912, inclusive.

Drainage area, including water surfaces	23.57 sq. miles
Area of water surfaces	1.00 sq. mile
Area of land surface	22.57 sq. miles

There are several swamps in the drainage area, the aggregate area of which is not definitely known but is approximately 2 sq. miles. No account was taken of these swamps in computing the accompanying tables.

Full corrections have been made for water drawn from or added to storage. The amount of storage in the ground surrounding the reservoirs is rather small, and no allowance has been made for such storage in the records of run-off. There is some percolation past the dam where the measurements are made, and some water is run through a small pipe to maintain the level of a

CAMBRIDGE, MASS., WATER WORKS, 1908.

Yield of Stony Brook at Stony Brook Dam. Total drainage area, 23.57 sq. miles. Area of land surface, 22.57 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	996.0	45	1 041.0	1.423	2.206	1.425	2.208	3.53	2.540	71.9	2.542	72.0
Feb.	824.5	68	892.5	1.259	1.949	1.305	2.020	4.83	2.102	43.5	2.179	45.1
Mar.	1 182.8	34	1 216.8	1.694	2.625	1.666	2.579	3.67	3.014	82.1	2.972	81.0
Apr.	712.3	−27	685.3	1.051	1.628	0.969	1.499	1.44	1.816	126.0	1.672	119.4
May	495.7	−5	490.7	0.710	1.098	0.671	1.038	4.19	1.263	30.1	1.197	28.6
June	223.9	−72	151.9	0.332	0.514	0.215	0.323	1.40	0.571	40.8	0.371	26.5
July	75.5	−37	38.5	0.108	0.167	0.053	0.082	3.86	0.193	5.0	0.094	2.4
Aug.	45.5	−22	23.5	0.065	0.101	0.032	0.050	4.26	0.116	2.7	0.057	1.3
Sept.	43.7	−56	−12.3	0.065	0.101	−0.017	−0.026	0.88	0.111	12.6	−0.030	−3.4
Oct.	15.0	−8	7.0	0.021	0.033	0.010	0.016	2.68	0.038	1.4	0.017	0.6
Nov.	33.0	−23	10.0	0.049	0.076	0.014	0.022	0.92	0.084	9.1	0.024	2.6
Dec.	70.0	17	87.0	0.100	0.155	0.119	0.184	2.50	0.178	7.1	0.212	8.5
Year	4 717.9	−86	4 631.9	0.572	0.886	0.537	0.831	34.16	12.026	35.2	11.307	33.1

CAMBRIDGE, MASS., WATER WORKS, 1909.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	155.0	57	212.0	0.222	0.344	0.290	0.449	4.21	0.395	11.6	0.517	12.3
Feb.	1 196.6	71	1 267.6	1.893	2.930	1.921	2.973	5.14	3.050	59.3	3.095	60.2
Mar.	923.5	39	962.5	1.320	2.041	1.317	2.038	3.95	2.353	59.6	2.350	58.5
Apr.	966.0	17	983.0	1.424	2.203	1.390	2.152	3.95	2.463	62.3	2.399	60.7
May	694.7	−42	652.7	0.993	1.534	0.893	1.382	2.04	1.771	86.8	1.593	78.1
June	336.5	−42	294.5	0.497	0.768	0.417	0.646	3.11	0.858	27.6	0.719	23.1
July	71.6	−60	11.6	0.102	0.158	0.016	0.025	2.50	0.182	7.3	0.028	1.1
Aug.	48.9	−45	3.9	0.070	0.108	0.005	0.008	2.90	0.125	4.3	0.010	0.3
Sept.	67.5	9	76.5	0.100	0.155	0.108	0.167	4.66	0.172	3.7	0.187	4.0
Oct.	48.2	−34	14.2	0.069	0.107	0.019	0.029	1.18	0.123	10.4	0.035	3.0
Nov.	142.0	16	158.0	0.210	0.325	0.223	0.345	3.20	0.362	11.3	0.386	12.1
Dec.	168.6	48	216.6	0.242	0.374	0.296	0.458	4.26	0.430	10.1	0.529	12.4
Year	4 819.1	34	4 853.1	0.586	0.906	0.564	0.872	41.10	12.284	29.9	11.848	28.8

CAMBRIDGE, MASS., WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent
Jan.	964.4	70	1 034.4	1.377	2.131	1.414	2.188	4.98	2.459	49.4	2.524	50.7
Feb.	1 077.6	49	1 126.6	1.705	2.640	1.708	2.642	3.88	2.747	70.8	2.751	70.9
Mar.	1 378.2	−3	1 375.2	1.970	3.050	1.882	2.913	1.53	3.513	230.0	3.359	219.3
Apr.	434.9	−10	424.9	0.642	0.994	0.601	0.930	2.39	1.108	46.4	1.037	43.4
May	262.4	−60	202.4	0.376	0.582	0.277	0.429	1.03	0.669	64.9	0.494	48.0
June	303.5	−30	273.5	0.448	0.694	0.387	0.599	3.82	0.773	20.2	0.668	17.5
July	59.9	−72	−12.1	0.086	0.133	−0.017	−0.026	1.85	0.153	8.3	−0.030	−16.2
Aug.	90.6	−67	23.6	0.130	0.201	0.032	0.050	1.64	0.231	14.1	0.058	3.5
Sept.	43.6	−24	19.6	0.064	0.099	0.028	0.043	2.76	0.111	4.0	0.048	1.7
Oct.	76.4	−30	46.4	0.109	0.169	0.064	0.099	1.44	0.195	13.5	0.113	7.9
Nov.	101.9	31	132.9	0.151	0.234	0.188	0.291	4.03	0.260	6.4	0.324	8.0
Dec.	289.4	12	301.4	0.414	0.640	0.412	0.638	2.22	0.737	33.2	0.736	33.2
Year	5 082.8	−134	4 948.8	0.618	0.957	0.575	0.890	31.57	12.956	41.1	12.082	38.3

CAMBRIDGE, MASS., WATER WORKS, 1911.

Jan.	290.0	32	322.0	0.415	0.643	0.441	0.684	2.83	0.739	26.2	0.786	27.8
Feb.	371.9	33	404.9	0.588	0.910	0.613	0.949	2.93	0.948	32.4	0.989	33.8
Mar.	699.4	28	727.4	1.000	1.549	0.995	1.540	3.32	1.782	53.7	1.775	53.5
Apr.	589.3	−14	575.3	0.870	1.345	0.814	1.260	2.17	1.502	69.2	1.405	64.8
May	195.9	−66	129.9	0.280	0.434	0.178	0.275	0.65	0.500	76.9	0.317	48.8
June	190.8	−32	158.8	0.282	0.436	0.225	0.348	3.68	0.487	13.2	0.388	10.5
July	86.5	−27	59.5	0.124	0.192	0.081	0.125	4.40	0.220	5.0	0.145	3.3
Aug.	86.6	−6	80.6	0.124	0.192	0.110	0.170	5.14	0.221	4.3	0.196	3.8
Sept.	149.1	−9	140.1	0.220	0.341	0.198	0.307	3.61	0.380	10.5	0.342	9.5
Oct.	308.4	−3	305.4	0.441	0.684	0.418	0.648	2.96	0.786	26.6	0.746	25.2
Nov.	508.5	40	548.5	0.750	1.160	0.776	1.202	4.54	1.297	28.6	1.340	29.5
Dec.	515.9	37	552.9	0.739	1.141	0.757	1.172	3.64	1.315	36.1	1.350	37.1
Year	3 992.3	12	4 005.3	0.485	0.752	0.465	0.720	39.87	10.177	25.5	9.779	24.5

CAMBRIDGE, MASS., WATER WORKS, 1912.

Jan.	486.0	29	515.0	0.695	1.075	0.705	1.091	2.65	1.238	46.7	1.257	47.5
Feb.	765.3	24	789.3	1.170	1.812	1.154	1.790	2.43	2.010	82.7	1.927	79.3

pond below the dam. No allowance has been made in the records of run-off for these quantities, which may amount to from 2 to 4 per cent. of the total run-off of dry years. Most of the drainage area is gently undulating, and in some parts there are hills from 100 to 200 ft. high.

The elevation above sea level ranges from 70 to 380 ft. and averages about 180 ft.

The quantity of water drawn for use by the city is measured as it flows through the pipe leading from Stony Brook dam to Fresh Pond, and the quantity is roughly checked by the amount pumped from the pond for the supply of the city. The quantity of water wasted is determined from records of the depth on the

spillway of the Stony Brook dam. During the years under consideration, comparatively little water was wasted.

Standard rain gages are maintained at the Stony Brook and Hobbs Brook reservoirs by the keepers of the reservoirs, under the supervision of the superintendent of the water works and the city engineer.

HOLYOKE, MASS., WATER WORKS.

Manhan River.

Information furnished by James L. Tighe, consulting engineer.

The yield of the southwest branch of the Manhan River was measured at the confluence of Manhan and Tucker brooks in Southampton, Mass.

The records furnished cover the years 1899 and 1900, which were very dry, as well as the years 1908–1911, inclusive.

Drainage area, which includes practically no water surfaces, 13 sq. miles.

Area of undrained swamps, about 250 acres.

The drainage area is mountainous in character, with precipitous slopes. The soil is rocky and gravelly, with considerable humus in the wooded parts; about 65 per cent. is forested.

The elevation above the sea ranges from 440 ft. at the southerly end to 1 550 ft. at the watershed line, six miles north, and averages about 950 ft.

HOLYOKE, MASS., WATER WORKS, 1899.

Yield of southwest branch of the Manhan River. Total drainage area (all land surface), 13 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu Ft. per Sec.		Inches.	Per Cent.
January.	492.3	1.470	2.274	3.04	2.62	86.09
February.	263.1	0.723	1.118	3.36	1.16	34.66
March.	658.2	1.633	2.526	6.87	2.91	42.41
April	1 921.3	4.926	7.622	1.92	8.50	442.95
May.	332.9	0.826	1.278	1.31	1.47	112.48
June.	97.5	0.248	0.383	2.43	0.43	17.58
July.	146.9	0.364	0.563	5.07	0.65	12.81
August.	51.6	0.128	0.198	1.94	0.23	11.76
September.	116.2	0.298	0.461	5.01	0.51	10.26
October	79.6	0.198	0.303	1.31	0.35	26.89
November.	169.2	0.434	0.671	3.16	0.75	23.70
December	181.9	0.451	0.697	2.86	0.80	28.14
The Year.	4 510.7	0.975	1.508	38.28	20.38	53.29

HOLYOKE, MASS., WATER WORKS, 1900.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	190.2	0.472	0.733	3.59	0.84	23.45
February	1 510.4	4.150	6.421	10.28	6.69	65.04
March	1 128.7	2.801	4.344	5.54	4.99	90.16
April	774.0	1.985	3.071	1.88	3.42	181.75
May	613.0	1.521	2.353	4.44	2.71	61.11
June	145.8	0.374	0.578	1.78	0.64	36.26
July	60.0	0.149	0.235	2.49	0.16	10.67
August	68.3	0.170	0.263	3.91	0.30	7.72
September	30.7	0.079	0.122	2.11	0.13	6.42
October	73.6	0.183	0.283	3.42	0.32	9.52
November	387.3	0.993	1.536	4.31	1.71	39.77
December	383.2	0.951	1.471	3.27	1.70	51.87
The Year	5 365.2	1.152	1.784	47.02	23.61	50.21

HOLYOKE, MASS., WATER WORKS, 1908.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	716.7	1.778	2.751	3.41	3.17	93.03
February	515.6	1.463	2.263	4.84	2.44	50.45
March	966.4	2.472	3.825	3.44	4.41	128.22
April	758.5	1.945	3.009	3.19	3.36	105.25
May	1 146.1	2.841	4.400	7.19	5.07	70.56
June	287.4	0.737	1.140	1.70	1.27	74.83
July	169.3	0.420	0.649	4.40	0.75	17.04
August	138.4	0.343	0.530	4.10	0.61	14.94
September	66.4	0.170	0.269	1.85	0.29	15.88
October	96.0	0.238	0.368	2.62	0.42	16.22
November	98.7	0.253	0.391	1.02	0.43	42.84
December	110.8	0.275	0.425	2.91	0.49	16.85
The Year	5 070.3	1.078	1.668	40.67	22.71	55.80

HOLYOKE, MASS., WATER WORKS, 1909.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	275.1	0.683	1.056	4.33	1.02	28.12
February	754.3	2.072	3.206	6.41	3.34	52.08
March	963.6	2.391	3.699	5.29	4.26	80.54
April	1 486.5	3.812	5.898	6.45	6.58	102.01
May	628.4	1.559	2.412	4.00	2.78	69.54
June	287.2	0.736	1.107	3.12	1.27	40.73
July	50.6	0.126	0.194	1.16	0.22	19.31
August	115.7	0.287	0.444	4.70	0.51	10.90
September	119.0	0.305	0.471	4.36	0.53	12.08
October	72.2	0.179	0.276	1.32	0.32	24.23
November	75.4	0.193	0.298	2.34	0.33	14.25
December	171.8	0.426	0.659	3.64	0.76	20.90
The Year	4 999.8	1.064	1.643	47.12	21.92	46.52

HOLYOKE, MASS., WATER WORKS, 1910.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	983.3	2.425	3.751	7.97	4.33	54.29
February	323.1	0.888	1.374	6.88	1.43	20.79
March	1 485.8	3.687	5.705	1.60	6.57	411.06
April	1 127.6	2.891	4.473	5.36	4.99	93.13
May	563.0	1.397	2.161	3.58	2.49	69.62
June	465.9	1.195	1.849	3.70	2.06	55.75
July	53.9	0.134	0.207	1.67	0.24	14.29
August	101.1	0.251	0.388	4.48	0.45	9.99
September	75.6	0.194	0.300	3.07	0.33	10.90
October	52.9	0.131	0.202	0.72	0.23	32.50
November	176.2	0.452	0.699	5.59	0.78	13.95
December	105.5	0.262	0.405	1.87	0.46	24.99
The Year	5 513.9	1.159	1.793	46.49	21.36	52.39

HOLYOKE, MASS., WATER WORKS, 1911.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent
January	142.7	0.354	0.574	2.08	0.62	29.65
February	76.1	0.209	0.323	1.80	0.33	18.27
March	526.4	1.306	2.020	4.21	2.27	54.04
April	686.8	1.761	2.724	2.61	2.97	113.75
May	228.0	0.566	0.875	1.13	0.98	87.22
June	333.9	0.856	1.324	4.21	1.44	34.28
July	170.0	0.422	0.653	4.17	0.73	17.62
August	162.9	0.404	0.625	6.71	0.70	10.49
September	115.0	0.294	0.455	4.57	0.49	10.88
October	980.5	2.433	3.764	8.86	4.24	47.83
November	527.4	1.352	2.092	2.57	2.28	88.70
December	413.6	1.026	1.587	2.98	1.79	59.99
The Year	4 363.3	0.915	1.461	45.90	18.84	41.04

The discharge measurements were made at two sharp crested weirs, one on each brook, using a hook gage to determine the heights. Readings were usually taken twice a day, and more frequently in rainy weather.

Records of precipitation were obtained from a standard rain gage 8 in. in diameter, located 10 in. above the surface of the ground near the weirs. The snowfall was determined from melting the snow collected in the gage.

Judging from experience elsewhere, the average precipitation on the drainage area would be greater than that recorded, because of the much higher elevation of a large portion of the area.

METROPOLITAN WATER WORKS.

Wachusett Drainage Area.

Information furnished by Dexter Brackett, chief engineer.

The records presented give the yield of this drainage area at the Wachusett Dam for the years 1908 to July, 1914, inclusive.

Drainage area, including water surfaces		118.19 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	8.59	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 0.68 sq. miles of drained swamps	0.20	
40 per cent. of 2.91 sq. miles of undrained swamps	1.16	
Total area reckoned as water surfaces		9.95 sq. miles
Area of land (upland) surface		108.24 sq. miles

The division of swamps into equivalent water surfaces and upland, as above indicated, has already been discussed in the report.

Full corrections are made for the water drawn from or added to storage, except that no allowance is made for the storage in the ground surrounding the reservoir. Such storage, although quite large in total amount, is small in proportion to the storage in the reservoir.

There is no appreciable percolation past the main dam or the south dike of the reservoir, but about one per cent. of the flow in the years 1908 to 1913, inclusive, percolated past the location of the north dike. Allowance was made for this percolation in and after 1910, but not in the previous years. Some water was diverted to the city of Worcester after August 1, 1911, and due allowance has been made therefor in the records.

The drainage area is generally hilly, and increasingly so toward the western portion of the area. The soil of the lower lands is generally sandy and gravelly, while that of many of the hills consists of unmodified drift. From one third to one half of the area is forested. The trees are cut from time to time and are replaced by a new growth. There is considerable ground water stored in the sand and gravel beds, which assists in equalizing the natural flow of the streams.

The elevation above sea level ranges from 390 to 2 108 ft. and averages about 750 ft.

During the period under consideration nearly all the water has been discharged through the Wachusett aqueduct and most of the time measured over a weir which was calibrated by current meter measurements made in the aqueduct. The depth on the weir was measured by an automatic recording float gage. In the latter part of 1911, a change in the method of measurements was made, caused by the introduction of hydro-electric machinery, and Venturi meters calibrated by current meter measurements were used to determine the flow. The quantity of water wasted at the spillway of the dam during the period under consideration amounted to only one per cent. of the yield, so that there has been practically no error due to spillway measurements.

The precipitation is measured at four stations, well distributed

METROPOLITAN WATER WORKS, 1908.

Yield of Wachusett drainage area. Total drainage area, 118.19 sq. miles. Area of land surface, 108.24 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected. Land Surface.		Precipitation Collected. Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	5 965.8	403	6 368.8	1.780	2.754	1.738	2.689	3.40	3.17	93.2	3.10	91.3
Feb.	5 320.5	628	5 948.5	1.696	2.624	1.736	2.685	4.82	2.83	58.7	2.90	60.1
Mar.	7 847.7	183	8 030.7	2.340	3.622	2.192	3.391	2.77	4.17	150.5	3.91	141.2
Apr.	4 560.8	−61	4 499.8	1.406	2.177	1.269	1.964	2.62	2.42	92.4	2.19	83.5
May	5 030.4	153	5 183.4	1.499	2.319	1.415	2.188	5.34	2.67	50.0	2.52	47.3
June	2 163.3	−734	1 429.3	0.667	1.032	0.403	0.624	1.29	1.15	89.1	0.70	53.9
July	1 168.2	−361	807.2	0.348	0.538	0.220	0.311	3.85	0.62	16.1	0.39	10.2
Aug.	1 455.8	167	1 622.8	0.434	0.672	0.443	0.685	6.49	0.77	11.9	0.79	12.2
Sept.	819.6	−509	310.6	0.253	0.391	0.088	0.136	1.04	0.44	42.3	0.15	14.5
Oct.	742.9	−163	579.9	0.221	0.342	0.158	0.245	2.13	0.39	18.3	0.28	13.3
Nov.	633.3	−189	444.3	0.195	0.302	0.125	0.194	1.05	0.34	32.4	0.22	20.6
Dec.	1 183.2	236	1 419.2	0.353	0.548	0.387	0.599	3.03	0.63	20.8	0.69	22.8
Year	36 891.5	−247	36 644.5	0.931	1.440	0.847	1.311	37.83	19.60	51.8	17.84	47.2

METROPOLITAN WATER WORKS, 1909.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation, Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 791.6	377	2 168.6	0.531	0.827	0.592	0.916	3.52	0.95	27.0	1.056	30.0
Feb.	7 711.5	748	8 459.5	2.542	3.935	2.556	3.655	6.10	4.10	67.2	4.118	67.5
Mar.	7 387.3	414	7 801.3	2.202	3.410	2.129	3.294	4.38	3.93	89.7	3.798	86.8
Apr.	8 129.0	459	8 588.0	2.500	3.870	2.422	3.748	5.71	4.32	75.6	4.181	73.3
May	4 752.2	−311	4 441.2	1.416	2.192	1.212	1.876	2.65	2.53	95.4	2.162	81.7
June	2 672.3	−433	2 239.3	0.824	1.276	0.632	0.977	3.03	1.42	46.9	1.091	36.0
July	1 149.0	−295	854.0	0.345	0.534	0.233	0.361	4.25	0.61	14.4	0.416	9.8
Aug.	1 030.7	−322	708.7	0.307	0.475	0.193	0.299	3.59	0.55	15.3	0.345	9.6
Sept.	772.9	−37	735.9	0.238	0.368	0.208	0.321	3.90	0.41	10.5	0.358	9.2
Oct.	572.0	−243	329.0	0.171	0.265	0.090	0.139	1.70	0.30	17.6	0.160	9.4
Nov.	1 376.7	−90	1 286.7	0.424	0.656	0.363	0.561	1.68	0.73	43.5	0.627	37.2
Dec.	1 581.9	386	1 967.9	0.472	0.731	0.537	0.831	3.99	0.84	21.0	0.958	24.0
Year	38 927.1	653	39 580.1	0.985	1.525	0.918	1.420	44.50	20.69	46.5	19.270	43.3

METROPOLITAN WATER WORKS, 1910.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation, Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	6 005.1	759	6 764.1	1.790	2.770	1.846	2.857	5.86	3.20	54.6	3.293	56.2
Feb.	5 433.4	671	6 104.4	1.792	2.772	1.845	2.854	5.24	2.89	55.1	2.972	56.7
Mar.	9 774.7	−104	9 670.7	2.912	4.506	2.640	4.084	1.09	5.19	476.0	4.709	432.8
Apr.	3 659.2	7	3 666.2	1.127	1.745	1.034	1.600	3.01	1.94	64.5	1.785	59.2
May	2 631.2	−402	2 229.2	0.784	1.213	0.608	0.941	2.13	1.40	65.7	1.085	50.9
June	3 123.3	−203	2 920.3	0.962	1.489	0.824	1.274	4.36	1.66	38.1	1.422	32.6
July	985.6	−759	226.6	0.294	0.455	0.062	0.096	1.52	0.52	34.2	0.110	7.2
Aug.	953.9	−273	680.9	0.287	0.444	0.186	0.288	3.87	0.51	13.2	0.331	8.6
Sept.	722.2	−209	513.2	0.223	0.345	0.115	0.224	2.86	0.38	13.3	0.250	8.7
Oct.	530.7	−280	250.7	0.158	0.245	0.068	0.106	1.40	0.28	20.0	0.122	8.7
Nov.	957.5	299	1 256.5	0.295	0.456	0.354	0.548	4.17	0.51	12.2	0.612	14.7
Dec.	1 307.5	125	1 432.5	0.390	0.604	0.391	0.605	2.34	0.70	29.9	0.697	29.8
Year	36 084.3	−369	35 715.3	0.913	1.413	0.828	1.281	37.85	19.18	50.7	17.388	45.9

METROPOLITAN WATER WORKS, 1911.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation, Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	2 542.6	290	2 832.6	0.758	1.173	0.773	1.196	2.91	1.35	46.4	1.379	47.5
Feb.	1 864.6	203	2 067.6	0.615	0.952	0.625	0.967	2.43	0.99	40.7	1.007	41.4
Mar.	4 599.6	308	4 907.6	1.371	2.122	1.339	2.072	3.79	2.44	64.4	2.389	63.0
Apr.	5 056.2	−118	4 938.2	1.556	2.409	1.393	2.155	2.22	2.68	120.7	2.404	108.5
May	2 158.7	−471	1 687.7	0.643	0.995	0.461	0.713	1.59	1.15	72.4	0.822	51.6
June	1 767.3	−523	1 244.3	0.542	0.839	0.351	0.543	2.37	0.94	39.6	0.606	25.5
July	765.0	−558	207.0	0.228	0.353	0.057	0.087	2.53	0.41	16.2	0.101	4.0
Aug.	696.1	−7	689.1	0.208	0.322	0.188	0.291	5.46	0.37	6.8	0.335	6.1
Sept.	812.2	−169	643.2	0.250	0.387	0.181	0.281	3.04	0.43	14.1	0.313	10.3
Oct.	2 311.5	318	2 629.5	0.689	1.066	0.718	1.111	5.24	1.23	23.5	1.280	24.4
Nov.	3 380.3	288	3 668.3	1.041	1.612	1.035	1.601	4.14	1.80	43.5	1.786	43.1
Dec.	3 679.0	229	3 908.0	1.096	1.697	1.067	1.650	3.01	1.96	65.1	1.903	63.2
Year	29 633.1	−219	29 423.1	0.750	1.161	0.682	1.055	38.73	15.75	40.7	14.325	37.0

METROPOLITAN WATER WORKS, 1912.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected. Land Surface.		Precipitation Collected. Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	2 609.8	250	2 859.8	0.778	1.204	0.781	1.208	2.57	1.39	54.1	1.392	54.2
Feb.	2 963.2	214	3 177.2	0.946	1.464	0.927	1.434	2.42	1.58	65.3	1.547	63.8
Mar.	9 739.0	633	10 372.0	2.903	4.490	2.831	4.380	5.69	5.18	91.0	5.050	88.8
Apr.	7 901.4	186	8 087.4	2.433	3.770	2.280	3.530	4.06	4 20	103.5	3.938	97.0
May	6 359.4	224	6 583.4	1.895	2.930	1.797	2.780	5.76	3.38	58.7	3.206	55.7
June	2 048.7	−875	1 173.7	0.630	0.975	0.331	0.512	0.48	1.09	227.0	0.571	119.6
July	1 063.0	−570	493.0	0.318	0.493	0.135	0.208	2.65	0.56	21.1	0.240	9.1
Aug.	899.2	−440	459.2	0.268	0.415	0.125	0.194	2.89	0.48	16.6	0.224	7.7
Sept.	641.8	−325	316.8	0.197	0.305	0.089	0.138	2.17	0.31	15.7	0.154	7.1
Oct.	634.8	−104	530.8	0.189	0.293	0.145	0.224	2.53	0.34	13.4	0.258	10.2
Nov.	1 183.6	382	1 565.6	0.365	0.565	0.442	0.683	4.02	0.63	15.7	0.762	18.9
Dec.	2 361.3	543	2 904.3	0.704	1.090	0.794	1.229	4.95	1.25	25.2	1.414	29.2
Year	38 405.2	118	38 523.2	0.970	1.501	0.891	1.378	40.19	20.42	50.8	18.756	46.7

METROPOLITAN WATER WORKS, 1913.

Jan.	4 795.7	385	5 180.7	1.429	2.212	1.414	2.188	3.38	2.55	7.54	2.52	74.7
Feb.	2 628.4	241	2 869.4	0.868	1.343	0.867	1.341	2.55	1.40	54.9	1.40	54.7
Mar.	7 654.5	636	8 290.5	2.282	3.530	2.263	3.501	5.58	4.07	72.9	4.04	72.4
Apr.	7 228.1	159	7 387.1	2.226	3.445	2.083	3.223	3.90	3.84	98.5	3.60	92.2
May	3 934.8	−130	3 804.8	1.173	1.815	1.038	1.607	3.71	2.09	56.4	1.85	49.9
June	1 795.4	−803	992.4	0.553	0.856	0.280	0.433	0.90	0.96	106.7	0.48	38.8
July	687.1	−617	70.1	0.205	0.317	0.019	0.030	2.37	0.37	15.6	0.03	1.4
Aug.	630.8	−412	218.8	0.188	0.291	0.060	0.092	3.05	0.34	11.1	0.11	3.4
Sept.	722.1	53	775.1	0.222	0.344	0.219	0.338	4.44	0.38	8.6	0.38	8.5
Oct.	2 015.2	469	2 484.2	0.601	0.930	0.678	1.049	6.02	1.07	17.8	1.21	20.1
Nov.	2 283.9	56	2 339.9	0.704	1.090	0.660	1.021	2.59	1.21	46.7	1.14	43.9
Dec.	3 298.8	201	3 499.8	0.983	1.522	0.955	1.478	2.73	1.75	64.1	1.70	62.5
Year	37 674.8	238	37 912.8	0.953	1 476	0.879	1.360	41.22	20.03	48 6	18.46	44.8

METROPOLITAN WATER WORKS, 1914.

Total drainage area, 108.84 sq. miles. Area of land surface, 99.15 sq. miles.

Jan.	2 950	389	3 339	0.960	1.485	0.990	1.532	3.40	1.71	50.3	1.77	52.1
Feb.	3 190	409	3 599	1.149	1.778	1.181	1.827	3.58	1.85	51.7	1.90	53.1
Mar.	10 147	436	10 583	3.302	5.112	3.137	4.853	4.33	5.89	133.8	5.60	129.3
Apr.	8 140	327	8 467	2.738	4.236	2.593	4.012	4.91	4.72	96.2	4.48	91.2
May	5 978	−245	5 733	1.945	3.010	1.699	2.629	3.01	3.47	105.2	3.03	100.7
June	1 630	−595	1 035	0.548	0.849	0.317	0.490	2.00	1.06	52.8	0.55	27.4
July	1 454	−343	1 111	0.473	0.732	0.329	0.510	3.92	1.18	30 2	0.59	15.0

over the drainage area, by rain gages 14.853 in. in diameter, set with their tops about 12 in. above the ground. The depth of precipitation is determined by weight, one ounce representing, with gages of this size, a depth of 0.01 in. of precipitation. The snowfall is generally measured at smooth platforms level with the ground in places sheltered from the wind. A section of snow of the same diameter of the rain gage is collected and weighed to obtain the depth of precipitation. The conditions during the period under consideration have been very favorable for ascertaining accurately the yield from this drainage area.

METROPOLITAN WATER WORKS.

Sudbury River.

Information furnished by Dexter Brackett, chief engineer.

The records presented cover two dry periods, the first from 1879 to 1884, and the second from 1908 to February, 1912. As there was a material change in the conditions between these two periods, both will be described.

The following statements relate to the years 1908–1912:

The yield measured is that of the river above Dam No. 1, and that of Farm Pond, which is below the dam.

Drainage area, including water surfaces		75.20 sq. miles
Area of water surfaces of reservoirs, ponds, and streams	4.89	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 1.47 sq. miles of drained swamps	0.44	
40 per cent. of 5.69 sq. miles of undrained swamps	2.28	
Total area reckoned as water surfaces		7.61 sq. miles
Area of land (upland) surface		67.59 sq. miles

Full corrections are made for the water drawn from or added to storage except that no allowance is made for the storage in the ground surrounding the reservoirs.

There is no appreciable leakage or percolation into or out of the drainage area, but considerable water is diverted into and from it in connection with water supply and sewerage works.

Due allowance has been made for all of these diversions.

There are extensive flat areas occupied by swamps and reservoirs as above stated. Elsewhere the slopes are generally quite steep.

About one third of the area is forested. The woods are cleared from time to time but are allowed to grow up again.

The elevation above the sea ranges from 165 to about 500 ft., and averages about 300 ft.

During the years under consideration it has not been feasible to measure the amount of run-off from the Sudbury drainage area with the degree of accuracy attained before 1898. Before that

year the larger part of the water was measured through the aqueduct except during the spring when considerable water went over the spillways or through the waste gates at the lower dam.

Beginning in 1898, the greater part of the water used by the Metropolitan Water District has been drawn from the Wachusett reservoir into the Sudbury reservoir, and the water from the larger part of the Sudbury drainage area has been allowed to waste over the dams during the seasons of low flow as well as at other times, diminishing the accuracy of the measurement. Moreover, the unavoidable errors in the measurement of the large quantity of Wachusett water into and out of the Sudbury drainage area naturally affect the accuracy of the Sudbury records, especially at times of low flow. In 1898 the area of water surfaces of the Sudbury drainage area was greatly increased and the summer flow was consequently affected to a greater extent by evaporation. It is estimated that the total degree of error may average about five per cent.

The amount of precipitation is determined in the manner already described for the Wachusett drainage area, and the same number of gages are in use.

The following statements relate to the period 1879–1884:

During the years 1879–1880 measurements of the flow of the river were made at a temporary wooden dam below Dam No. 1.

Drainage area, including water surfaces		78.24 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	2.26	
40 per cent. of 7.34 sq. miles of undrained swamps . . .	2.94	
Total area reckoned as water surfaces		5.20 sq. miles
Area of land (upland) surface		73.04 sq. miles

At the beginning of the year 1881, the point of measurement was transferred from the temporary wooden dam to Dam No. 1 and the conditions were as follows:

Drainage area, including water surfaces	75.20 sq. miles
Total area reckoned as water surfaces as before	5.20 sq. miles
Area of land (upland) surface	70.00 sq. miles

METROPOLITAN WATER WORKS, 1879.

Yield of Sudbury River above Dam No. 1 and of Farm Pond. Total drainage area, 78.24 sq. miles. Area of land surface, 73.04 sq. miles.

Month.	Yield of Drainage Area in Million Gallons. Land Surface.	Water Surface.	Total Area.	Yield per Sq. Mile of Land Surface. Mil. Gal. per Day.	Cu. Ft. per Sec.	Yield per Sq. Mile of Total Area. Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Land Surface. Inches.	Per Cent.	Total Area. Inches.	Per Cent.
Jan.	1 573.2	125	1 698.2	0.696	1.077	0.700	1.083	2.47	1.24	50.2	1.249	50.4
Feb.	3 526.9	221	3 747.9	1.724	2.670	1.711	2.647	3.56	2.78	78.1	2.756	77.4
Mar.	5 345.4	306	5 651.4	2.362	3.658	2.330	3.605	5.14	4.22	82.1	4.156	80.9
Apr.	7 162.7	151	7 313.7	3.270	5.062	3.116	4.821	4.71	5.64	119.8	5.379	114.1
May	2 934.4	−233	2 701.4	1.295	2.005	1.114	1.723	1.60	2.31	144.5	1.987	125.8
June	1 113.2	−143	970.2	0.508	0.786	0.413	0.640	3.79	0.88	23.2	0.713	18.8
July	548.7	−167	381.7	0.242	0.375	0.157	0.243	3.93	0.43	10.9	0.281	7.1
Aug.	875.3	83	958.3	0.386	0.598	0.395	0.611	6.51	0.69	10.6	0.705	10.8
Sept.	521.3	−191	330.3	0.238	0.368	0.141	0.218	1.88	0.41	21.8	0.243	12.9
Oct.	371.5	−200	171.5	0.164	0.254	0.071	0.109	0.81	0.29	35.8	0.126	15.6
Nov.	446.5	36	482.5	0.204	0.316	0.206	0.318	2.68	0.35	13.1	0.355	13.2
Dec.	874.8	247	1 121.8	0.386	0.598	0.463	0.716	4.34	0.69	15.9	0.825	19.0
Year	25 293.9	235	25 528.9	0.949	1.469	0.894	1.383	41.42	19.93	48.1	18.775	45.3

METROPOLITAN WATER WORKS, 1880.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation. Inches.	Land Inches.	Per Cent.	Total Inches.	Per Cent.
Jan.	2 481.0	235	2 716.0	1.095	1.695	1.120	1.733	3.57	1.95	54.6	2.000	56.0
Feb.	3 790.4	264	4 054.4	1.871	2.899	1.787	2.765	3.98	2.99	75.1	2.982	74.9
Mar.	3 186.2	146	3 332.2	1.406	2.178	1.374	2.126	3.31	2.51	75.8	2.451	73.9
Apr.	2 731.0	12	2 743.0	1.247	1.931	1.169	1.808	3.10	2.15	69.4	2.017	65.0
May	1 483.0	−236	1 247.0	0.655	1.014	0.514	0.796	1.84	1.17	63.6	0.917	50.0
June	719.7	−308	411.7	0.329	0.509	0.175	0.271	2.14	0.57	26.6	0.303	14.2
July	401.7	26	427.7	0.177	0.274	0.176	0.273	6.27	0.32	5.1	0.315	5.0
Aug.	422.2	−134	288.2	0.186	0.288	0.119	0.184	4.01	0.33	8.2	0.212	5.3
Sept.	412.4	−224	188.4	0.188	0.291	0.080	0.124	1.60	0.32	20.0	0.138	8.6
Oct.	196.5	50	246.5	0.086	0.133	0.102	0.157	3.74	0.15	4.0	0.181	4.9
Nov.	521.7	−40	481.7	0.238	0.368	0.205	0.318	1.79	0.41	22.9	0.354	19.9
Dec.	311.8	113	424.8	0.138	0.214	0.175	0.271	2.83	0.25	8.8	0.312	11.1
Year	16 657.6	−96	16 561.6	0.650	1.006	0.578	0.895	38.18	13.12	34.4	12.182	31.9

METROPOLITAN WATER WORKS, 1881.

Total drainage area 75.2 sq. miles. Area of land surface, 70.0 sq. miles.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation. Inches.	Land Inches.	Per Cent.	Total Inches.	Per Cent.
Jan.	568.9	398	966.9	0.262	0.405	0.415	0.642	5.56	0.47	8.5	0.740	13.3
Feb.	2 939.5	316	3 255.5	1.499	2.320	1.546	2.392	4.65	2.41	51.8	2.491	53.6
Mar.	8 971.6	362	9 333.6	4.133	6.400	4.004	6.195	5.73	7.37	128.6	7.142	124.6
Apr.	3 574.7	−87	3 487.7	1.702	2.635	1.546	2.392	2.00	2.94	147.0	2.669	133.4
May	2 331.6	−82	2 249.6	1.075	1.664	0.965	1.493	3.51	1.92	54.7	1.721	49.0
June	3 031.8	−14	3 017.8	1.444	2.234	1.338	2.070	5.39	2.49	46.2	2.309	42.8
July	971.3	−327	644.3	0.447	0.692	0.276	0.428	2.35	0.80	34.0	0.493	21.0
Aug.	715.2	−370	345.2	0.330	0.514	0.148	0.229	1.36	0.59	43.4	0.264	19.5
Sept.	574.9	−130	444.9	0.274	0.424	0.197	0.305	2.62	0.47	17.9	0.340	13.0
Oct.	449.6	−17	432.6	0.207	0.320	0.186	0.287	2.95	0.37	12.5	0.331	11.2
Nov.	733.0	158	891.0	0.349	0.540	0.395	0.611	4.09	0.60	14.7	0.682	16.7
Dec.	1 589.9	217	1 806.9	0.732	1.133	0.775	1.199	3.96	1.31	33.1	1.383	34.9
Year	26 452.0	424	26 870.0	1.035	1.602	0.979	1.515	44.17	21.74	49.3	20.565	46.6

METROPOLITAN WATER WORKS, 1882.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation. Inches.	Land Inches.	Per Cent.	Total Inches.	Per Cent.
Jan.	2 447.2	445	2 892.2	1.127	1.745	1.241	1.920	5.95	2.01	33.8	2.213	37.2
Feb.	4 745.3	315	5 060.3	2.420	3.745	2.403	3.718	4.55	3.90	85.7	3.872	85.2
Mar.	6 532.9	85	6 617.9	3.011	4.662	2.839	4.392	2.65	5.37	202.8	5.064	191.2
Apr.	2 060.8	−104	1 956.8	0.982	1.519	0.867	1.342	1.82	1.69	92.8	1.497	82.1
May	2 956.9	54	3 010.9	1.362	2.109	1.292	1.998	5.06	2.43	48.0	2.304	45.5
June	1 544.3	−351	1 193.3	0.735	1.137	0.529	0.818	1.66	1.27	76.5	0.913	54.9
July	580.1	−379	201.1	0.268	0.415	0.086	0.133	1.77	0.48	27.1	0.154	8.7
Aug.	462.9	−334	128.9	0.213	0.330	0.055	0.086	1.67	0.38	22.8	0.099	5.9
Sept.	293.5	398	691.5	0.140	0.216	0.307	0.474	8.74	0.24	2.7	0.529	6.1
Oct.	793.7	−96	697.7	0.366	0.567	0.299	0.463	2.07	0.65	31.4	0.534	25.7
Nov.	568.3	−96	472.3	0.272	0.421	0.209	0.324	1.15	0.47	40.9	0.362	31.5
Dec.	663.6	70	733.6	0.306	0.474	0.315	0.487	2.30	0.55	23.9	0.561	24.5
Year	23 649.5	7	23 656.5	0.926	1.434	0.862	1.334	39.39	19.44	49.4	18.102	46.0

METROPOLITAN WATER WORKS, 1883.

Month.	Yield of Drainage Area in Million Gallons. Land Surface.	Water Surface.	Total Area.	Yield per Sq. Mile of Land Surface. Mil. Gal. per Day.	Cu. Ft. per Sec.	Yield per Sq. Mile of Total Area. Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Land Surface. Inches.	Per Cent.	Total Area. Inches.	Per Cent.
Jan.	618.5	162	780.5	0.285	0.441	0.335	0.518	2.81	0.51	18.1	0.597	21.3
Feb.	1 927.4	247	2 174.4	0.984	1.522	1.033	1.598	3.86	1.58	40.9	1.664	43.1
Mar.	3 748.0	7	3 755.0	1.727	2.672	1.611	2.492	1.78	3.08	173.1	2.873	161.4
Apr.	3 147.5	−103	3 044.5	1.499	2.320	1.350	2.088	1.85	2.59	140.0	2.330	126.3
May	2 211.3	−26	2 185.3	1.019	1.578	0.937	1.450	4.18	1.82	43.5	1.673	40.0
June	959.9	−283	676.9	0.457	0.708	0.300	0.464	2.40	0.79	32.9	0.518	21.6
July	562.9	−294	268.9	0.260	0.402	0.115	0.178	2.68	0.46	17.2	0.206	7.7
Aug.	588.1	−405	183.1	0.271	0.420	0.079	0.122	0.74	0.48	64.8	0.140	19.1
Sept.	421.9	−216	205.9	0.201	0.310	0.091	0.141	1.52	0.35	23.0	0.157	10.4
Oct.	235.2	198	433.2	0.108	0.167	0.186	0.288	5.60	0.19	3.4	0.331	5.9
Nov.	496.7	−35	461.7	0.236	0.365	0.205	0.317	1.81	0.41	22.6	0.354	19.5
Dec.	293.1	158	451.1	0.135	0.209	0.194	0.299	3.55	0.24	6.8	0.345	9.7
Year	15 210.5	−590	14 620.5	0.595	0.922	0.533	0.824	32.78	12.50	38.1	11.188	34.1

METROPOLITAN WATER WORKS, 1884.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 967.9	352	2 319.9	0.907	1.403	0.995	1.540	5.08	1.62	31.8	1.77	34.8
Feb.	5 703.3	494	6 197.3	2.810	4.348	2.842	4.397	6.55	4.69	71.6	4.71	72.4
Mar.	8 552.3	272	8 824.3	3.941	6.098	3.785	5.857	4.72	7.04	149.2	6.75	143.0
Apr.	6 308.3	129	6 437.3	3.004	4.648	2.853	4.415	4.40	5.18	117.7	4.92	111.7
May	2 491.1	−89	2 402.1	1.148	1.776	1.030	1.594	3.47	2.05	59.1	1.84	53.0
June	1 129.0	−190	939.0	0.538	0.832	0.416	0.644	3.44	0.93	27.1	0.72	20.9
July	730.5	−209	521.5	0.337	0.521	0.224	0.346	3.67	0.60	16.3	0.40	10.9
Aug.	675.5	−77	598.5	0.311	0.481	0.257	0.397	4.65	0.55	11.8	0.46	9.9
Sept.	392.1	−293	99.1	0.187	0.289	0.044	0.068	0.86	0.32	37.2	0.08	9.4
Oct.	252.8	−59	193.8	0.117	0.181	0.083	0.129	2.48	0.21	8.5	0.15	6.0
Nov.	359.3	36	395.3	0.171	0.264	0.175	0.271	2.65	0.29	10.9	0.30	11.3
Dec.	1 829.0	327	2 156.0	0.843	1.304	0.925	1.431	5.17	1.50	29.0	1.65	31.9
Year	30 391.1	693	31 084.1	1.186	1.834	1.129	1.747	47.14	21.98	53.0	23.78	50.4

METROPOLITAN WATER WORKS, 1908.

Total drainage area, 75.20 sq. miles. Area of land surface, 67.59 sq. miles.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	4 143.6	344	4 487.6	1.979	3.062	1.925	2.978	3.60	3.53	98.1	3.434	95.4
Feb.	2 895.4	455	3 350.4	1.477	2.284	1.536	2.377	4.56	2.46	53.9	2.564	56.3
Mar.	4 985.7	276	5 261.7	2.379	3.680	2.257	3.492	3.82	4.24	111.0	4.026	105.5
Apr.	2 663.4	−143	2 520.4	1.315	2.034	1.117	1.729	1.88	2.27	120.8	1.929	102.6
May	2 300.5	137	2 437.5	1.099	1.701	1.046	1.618	5.51	1.96	35.6	1.865	33.9
June	1 052.6	−614	438.6	0.520	0.805	0.194	0.301	0.86	0.90	104.7	0.335	38.9
July	264.2	−297	−32.8	0.126	0.195	−0.014	−0.022	3.71	0.23	6.2	−0.025	−0.7
Aug.	358.7	−122	236.7	0.171	0.265	0.102	0.157	4.57	0.31	6.8	0.181	4.0
Sept.	227.5	−412	−184.5	0.112	0.173	−0.082	−0.127	0.97	0.19	19.6	−0.141	−14.5
Oct.	195.9	−87	108.9	0.094	0.145	0.047	0.072	2.55	0.17	6.7	0.083	3.3
Nov.	321.9	−162	159.9	0.159	0.246	0.071	0.110	0.98	0.27	27.6	0.122	12.5
Dec.	110.1	207	317.1	0.053	0.082	0.136	0.210	3.14	0.09	2.9	0.243	7.7
Year	19 519.5	−418	19 101.5	0.791	1.224	0.694	1.074	36.15	16.62	46.0	14.616	40.4

METROPOLITAN WATER WORKS, 1909.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	521.7	393	914.7	0.249	0.385	0.392	0.607	3.98	0.44	11.1	0.700	17.6
Feb.	4 197.0	617	4 814.0	2.218	3.430	2.286	3.537	5.79	3.57	61.7	3.684	63.6
Mar.	3 710.2	332	4 042.2	1.772	2.742	1.734	2.683	4.26	3.16	74.1	3.093	72.7
Apr.	3 659.9	222	3 881.9	1.805	2.793	1.721	2.662	4.67	3.11	66.6	2.970	63.6
May	2 605.9	−266	2 339.9	1.269	1.962	1.004	1.553	2.43	2.23	91.7	1.791	73.8
June	898.2	−358	540.2	0.443	0.686	0.239	0.370	2.81	0.77	27.4	0.413	14.7
July	292.8	−575	−282.2	0.140	0.217	−0.121	−0.187	1.59	0.25	15.7	−0.216	−13.5
Aug.	231.8	−336	−104.2	0.111	0.172	−0.045	−0.069	2.93	0.19	6.5	−0.080	−2.7
Sept.	254.2	82	336.2	0.126	0.195	0.149	0.231	4.74	0.22	4.6	0.257	5.4
Oct.	142.3	−262	−119.7	0.068	0.105	−0.051	−0.079	1.12	0.12	10.7	−0.092	−8.2
Nov.	39.6	146	185.6	0.020	0.031	0.082	0.127	3.38	0.03	0.9	0.142	4.2
Dec.	280.6	332	612.6	0.134	0.207	0.263	0.407	4.05	0.24	5.9	0.469	11.6
Year	16 834.2	327	17 161.2	0.682	1.055	0.625	0.967	41.75	14.33	34.3	13.131	31.5

METROPOLITAN WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	2 888.6	584	3 472.6	1.378	2.133	1.490	2.305	5.39	2.46	45.6	2.657	49.3
Feb.	3 372 0	521	3 893.0	1.611	2.494	1.849	2.861	5.06	2.87	56.8	2.979	58.9
Mar.	4 666.2	−111	4 555.2	2.228	3.448	1.954	3.023	0.85	3.97	467.0	3.486	408.7
Apr.	1 522.0	−18	1 504.0	0.727	1.125	0.667	1.031	2.75	1.29	46.9	1.151	41.9
May	1 060.5	−414	646.5	0.507	0.785	0.277	0.429	1.29	0.90	69.8	0.495	38.3
June	1 277.8	−113	1 164.8	0.610	0.944	0.516	0.799	4.68	1.09	23.3	0.891	19.0
July	277.6	−516	−238.4	0.133	0.206	−0.102	−0.158	2.03	0.24	11.8	−0.182	−9.0
Aug.	207.5	−377	−169.5	0.099	0.153	−0.073	−0.113	2.62	0.18	6.9	−0.130	−5.0
Sept.	223.1	−212	11.1	0.107	0.166	0.005	0.008	2.49	0.19	7.6	0.008	0.3
Oct.	53.8	−172	−118.2	0.026	0.040	−0.051	−0.078	1.86	0.05	2.7	−0.091	−4.9
Nov.	152.7	245	397.7	0.073	0.113	0.176	0.273	4.13	0.13	3.1	0.304	7.4
Dec.	388.9	127	515.9	0.186	0.288	0.221	0.342	2.49	0.33	13.3	0.395	15.8
Year	16 090.7	−456	15 634.7	0.652	1.009	0.570	0.881	35.64	13.70	38.4	11.963	33.6

METROPOLITAN WATER WORKS, 1911.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation, Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	959.1	250	1 209.1	0.458	0.709	0.519	0.802	2.88	0.82	28.5	0.925	32.1
Feb.	1 250 8	224	1 474.8	0.661	1.022	0.700	1.084	2.77	1.07	38.6	1.128	40.7
Mar.	2 422.9	245	2 667.9	1.157	1.792	1.144	1.771	3.59	2.06	57.4	2.042	56.9
Apr.	3 237.3	−21	3 216.3	1.597	2.471	1.426	2.206	2.81	2.75	97.8	2.462	87.4
May	1 185.9	−445	740.9	0.568	0.879	0.318	0.492	1.01	1.01	100.0	0.567	56.1
June	862.1	−382	480.1	0.425	0.658	0.213	0.329	2.53	0.73	28.9	0.367	14.5
July	312.7	−346	−33.3	0.149	0.230	−0.014	−0.022	3.19	0.27	8.5	−0.025	−0.8
Aug.	117.5	−70	47.5	0.056	0.087	0.020	0.032	4.94	0.10	2.0	0.036	0.7
Sept.	337.5	−167	170.5	0.167	0.259	0.076	0.117	2.75	0.29	10.5	0.130	4.8
Oct.	626.1	64	690.1	0.299	0.463	0.296	0.458	3.69	0.53	14.4	0.528	14.3
Nov.	1 048.6	290	1 338.6	0.518	0.802	0.593	0.918	4.62	0.89	19.3	1.024	22.2
Dec.	1 856.4	261	2 117.4	0.886	1.371	0.908	1.405	3.60	1.58	43.9	1.620	45.0
Year	14 216.9	−97	14 119.9	0.577	0.893	0.514	0.796	38.38	12.10	31.5	10.804	28.2

METROPOLITAN WATER WORKS, 1912.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation, Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 446.4	251	1 697.4	0.681	1.054	0.728	1.127	2.94	1.20	40.7	1.299	44.1
Feb.	2 395.8	215	2 610.8	1.225	1.895	1.197	1.852	2.77	2.06	74.4	1.998	72.2

During the whole of this earlier period there was no appreciable leakage past the dams. Only a small quantity of water was diverted into and out of the drainage area by local water supplies, and no water was received from the Wachusett drainage area. In other respects, except for the building of additional storage reservoirs in the interval between the two periods, the conditions in each were substantially the same. On the whole, the conditions were much more favorable for accurate gaging in the earlier than in the later period.

METROPOLITAN WATER WORKS.

Lake Cochituate.

Information furnished by Dexter Brackett, chief engineer.

The records cover two dry periods, the first from 1879 to January, 1884, and the second from 1908 to 1912. The conditions changed but little between these two periods.

The yield measured is that at the outlet of the lake.

Drainage area, including water surfaces during the years 1879–1884 and 1908 and 1909		18.87 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	1.38	
40 per cent. of 0.93 sq. miles of undrained swamps	0.37	
Total area reckoned as water surfaces		1.75 sq. miles
Area of land (upland) surface		17.12 sq. miles

Full corrections are made for the water drained from or added to visible storage, but no allowance is made for a considerable amount of storage in the porous ground surrounding the lake.

There is some percolation from the lake where it is retained by natural sandy barriers, which is much larger when the lake is full than when it is drawn down. No allowance has been made for this percolation in the computations, but the resulting error is probably not more than two per cent.

During the period 1908–1912, considerable water was diverted into and from the drainage area in connection with water supply and sewerage works, for which due allowance has been made in the computations.

During the earlier period the water so diverted was a small quantity and no account was taken of it.

In 1910 the drainage area was diminished by the diversion in another direction of the flow from Dug Pond and its tributary area, reducing the drainage area, including water surfaces, to 17.8 sq. miles and the land surface to 16.12 sq. miles.

At the beginning of 1911, the construction of a drain to remove polluted water resulted in a further reduction of the drainage area of the lake, including water surfaces, to 17.58 sq. miles, and a corresponding reduction in the land surface to 15.90 sq. miles.

Most of the drainage area is nearly level or with gentle slopes, and but a small part of it is hilly.

The soil is sand and gravel; rather less than one third is forested and the remainder is cultivated or pasture land or is occupied by the towns upon the drainage area.

The elevation above the sea ranges from 140 to 300 ft. and averages about 180 ft.

During the earlier period water was discharged from the Sudbury River into Lake Cochituate to the extent of about 14 per cent. of the yield of the latter. This quantity was carefully measured before it entered the lake.

During the later period there was no such diversion.

The records of the earlier period were used only for determining the relative yield during the two periods, and are not reproduced here.

METROPOLITAN WATER WORKS, 1908.

Yield of Lake Cochituate. Total drainage area, 18.87 sq. miles. Area of land surface, 17.12 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	702.7	72.1	774.8	1.324	2.049	1.325	2.049	3.33	2.36	71.0	2.36	71.0
Feb.	754.4	98.8	853.2	1.519	2.351	1.559	2.412	4.30	2.53	58.8	2.60	60.5
Mar.	1 055.5	58.4	1 113.9	1.989	3.077	1.904	2.946	3.62	3.55	98.1	3.40	93.8
Apr.	594.8	−35.6	559.2	1.158	1.792	0.988	1.528	1.80	2.00	111.1	1.71	94.7
May	499.8	3.6	503.4	0.942	1.457	0.861	1.331	4.58	1.68	36.7	1.53	33.5
June	129.6	−14.4	115.2	0.252	0.390	0.203	0.315	0.82	0.44	53.5	0.35	42.8
July	154.7	−62.2	92.5	0.291	0.451	0.158	0.245	3.91	0.52	13.3	0.28	7.2
Aug.	115.1	−45.4	69.7	0.217	0.336	0.119	0.184	3.98	0.39	9.8	0.21	5.3
Sept.	89.3	−100.1	−10.8	0.174	0.269	−0.019	−0.030	0.77	0.30	39.0	−0.03	−4.3
Oct.	64.5	−23.6	40.9	0.122	0.188	0.070	0.108	2.37	0.22	9.3	0.12	5.3
Nov.	86.5	−41.6	44.9	0.168	0.261	0.079	0.123	0.85	0.29	34.1	0.14	16.1
Dec.	111.3	35.2	146.5	0.210	0.324	0.250	0.387	2.70	0.37	13.7	0.45	16.5
Year	4 358.2	−54.8	4 303.4	0.696	1.076	0.623	0.964	33.03	14.65	44.4	13.12	39.7

METROPOLITAN WATER WORKS, 1909.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	139.1	100.4	239.5	0.262	0.406	0.409	0.633	4.34	0.47	10.8	0.73	16.8
Feb.	951.2	138.6	1 089.8	1.984	3.070	2.063	3.191	5.66	3.20	56.5	3.32	58.7
Mar.	734.1	69.3	803.4	1.383	2.140	1.373	2.125	3.98	2.47	62.1	2.45	61.5
Apr.	738.4	46.5	784.9	1.438	2.224	1.387	2.145	4.50	2.48	55.1	2.39	53.2
May	533.8	−73.3	460.5	1.006	1.556	0.787	1.218	2.05	1.79	87.3	1.40	68.5
June	292.8	−74.1	218.7	0.570	0.882	0.386	0.598	3.09	0.98	31.7	0.67	21.6
July	193.9	−125.6	68.3	0.365	0.565	0.117	0.181	1.73	0.65	37.6	0.21	12.0
Aug.	239.7	−76.3	163.4	0.452	0.699	0.279	0.432	2.84	0.81	28.5	0.50	17.5
Sept.	235.2	5.6	240.8	0.458	0.709	0.425	0.658	4.33	0.79	18.2	0.74	17.0
Oct.	108.2	−54.4	53.8	0.204	0.316	0.092	0.142	1.06	0.36	34.0	0.16	15.5
Nov.	95.1	40.9	136.3	0.186	0.287	0.241	0.373	3.76	0.32	8.5	0.42	11.1
Dec.	138.3	72.5	210.8	0.261	0.403	0.360	0.558	4.10	0.47	11.5	0.64	15.7
Year	4 400.1	70.1	4 470.2	0.704	1.089	0.649	1.004	41.44	14.79	35.7	13.63	32.9

METROPOLITAN WATER WORKS, 1910.

Total drainage area, 17.8 sq. miles. Area of land surface, 16.12 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	748.3	116.1	864.4	1.497	2.317	1.567	2.424	5.11	2.67	52.2	2.80	54.7
Feb.	785.5	118.6	904.1	1.740	2.693	1.814	2.807	5.16	2.81	54.4	2.92	56.7
Mar.	886.9	−26.8	860.1	1.775	2.746	1.559	2.412	0.77	3.17	411.6	2.78	361.1
Apr.	403.2	−7.4	395.8	0.834	1.290	0.741	1.147	2.71	1.44	53.1	1.28	47.2
May	303.1	−88.1	215.0	0.607	0.938	0.390	0.603	1.33	1.08	81.2	0.70	52.3
June	382.0	−28.6	353.4	0.790	1.222	0.662	1.024	4.51	1.36	30.2	1.14	25.3
July	193.3	−103.6	89.7	0.387	0.598	0.163	0.252	2.23	0.69	30.9	0.29	13.0
Aug.	113.1	−108.3	4.8	0.226	0.350	0.009	0.013	1.58	0.40	25.3	0.02	1.0
Sept.	79.6	−44.8	34.8	0.165	0.255	0.065	0.101	2.50	0.28	11.2	0.11	4.5
Oct.	50.1	−37.6	12.5	0.100	0.155	0.023	0.035	1.80	0.18	10.0	0.04	2.2
Nov.	77.6	53.1	130.7	0.160	0.248	0.245	0.379	4.16	0.28	6.7	0.42	10.2
Dec.	149.8	30.8	180.6	0.300	0.464	0.327	0.506	2.61	0.54	20.7	0.58	22.4
Year	4 172.5	−126.6	4 045.9	0.709	1.097	0.623	0.964	34.47	14.90	43.2	13.08	37.9

METROPOLITAN WATER WORKS, 1911.

Total drainage area, 17.58 sq. miles. Area of land surface, 15.90 sq. miles.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation. Inches.	Land Inches.	Per Cent.	Total Inches.	Per Cent.
Jan.	221.6	50.4	272.0	0.450	0.696	0.497	0.768	2.74	0.80	29.2	0.89	32.3
Feb.	311.6	61.7	373.3	0.700	1.083	0.758	1.173	3.20	1.13	35.3	1.22	38.2
Mar.	565.2	46.4	611.6	1.147	1.774	1.122	1.736	3.31	2.05	61.9	2.00	60.5
Apr.	669.4	−7.0	662.4	1.403	2.171	1.256	1.943	2.73	2.42	88.6	2.17	79.4
May	199.5	−111.2	88.3	0.405	0.626	0.162	0.251	0.65	0.72	110.8	0.29	44.5
June	127.6	−87.9	39.7	0.268	0.414	0.075	0.116	2.53	0.46	18.2	0.13	5.1
July	91.7	−73.4	18.3	0.186	0.288	0.034	0.052	3.42	0.33	9.6	0.06	1.8
Aug.	190.3	−18.9	171.4	0.386	0.597	0.315	0.487	4.82	0.69	14.3	0.56	11.6
Sept.	217.8	−30.6	187.2	0.457	0.706	0.355	0.549	2.96	0.79	26.7	0.61	20.7
Oct.	267.7	9.1	276.8	0.543	0.840	0.508	0.786	3.53	0.97	27.5	0.91	25.7
Nov.	312.1	51.9	364.0	0.654	1.012	0.690	1.068	4.28	1.12	26.2	1.19	27.8
Dec.	487.7	60.8	548.5	0.989	1.531	1.006	1.557	3.74	1.77	47.3	1.79	46.4
Year	3 662.2	−48.7	3 613.5	0.631	0.976	0.563	0.871	37.91	13.25	35.0	11.82	31.2

METROPOLITAN WATER WORKS, 1912.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation. Inches.	Land Inches.	Per Cent.	Total Inches.	Per Cent.
Jan.	285.2	60.2	345.4	0.579	0.895	0.634	0.981	3.10	1.03	33.2	1.13	36.5
Feb.	545.5	41.9	587.4	1.183	1.830	1.152	1.783	2.51	1.98	78.9	1.92	76.6
Mar.	1 365.5	135.8	1 501.3	2.770	4.286	2.755	4.262	6.38	4.94	77.4	4.91	77.0
Apr.	996.5	34.7	1 031.2	2.089	3.232	1.955	3.025	4.16	3.61	86.8	3.38	81.1
May	768.1	22.5	790.6	1.558	2.411	1.451	2.245	5.23	2.78	53.2	2.59	49.5
June	290.2	−148.0	142.2	0.608	0.941	0.270	0.417	0.47	1.05	223.4	0.46	99.0
July	108.4	−86.5	21.9	0.220	0.340	0.040	0.062	3.00	0.39	13.0	0.07	2.4
Aug.	135.1	−93.5	41.6	0.274	0.424	0.076	0.118	2.26	0.49	21.7	0.14	6.0
Sept.	185.2	−65.6	119.6	0.388	0.601	0.227	0.351	1.82	0.67	36.8	0.39	21.5
Oct.	154.5	−4.8	149.7	0.313	0.485	0.275	0.425	2.99	0.56	18.7	0.49	16.4
Nov.	148.5	27.5	176.0	0.311	0.482	0.334	0.516	3.24	0.54	16.7	0.58	17.8
Dec.	238.5	97.1	335.6	0.484	0.749	0.616	0.953	4.96	0.86	17.3	1.10	22.1
Year	5 221.2	21.3	5 242.5	0.897	1.388	0.815	1.261	40.12	18.90	47.1	17.16	42.77

The discharge measurements are believed to be fairly accurate.

The precipitation is measured by a single gage at the lake of the same kind that is used on the Wachusett and Sudbury drainage areas.

SPRINGFIELD, MASS., WATER WORKS.

Westfield Little River.

Information furnished by E. E. Lochridge, chief engineer.

The yield for 1910 and 1911 was measured at the intake dam of the Springfield Water Works; in 1908 and 1909 it was measured at a point further upstream.

The records are for the years 1908–1911.

1908 and 1909:

Drainage area, including water surfaces	43.00 sq. miles.
Area of water surfaces (3 ponds)	0.35 sq. miles.
Area of land surface	42.65 sq. miles.

1910 and 1911:

Drainage area, including water surfaces	48.00 sq. miles.
Area of water surfaces	0.69 sq. miles.
Area of land surface	47.31 sq. miles.

Borden Brook Reservoir was first filled in 1910, which accounts for the changed area of water surfaces.

There are no drained swamps. Swamps of any type are high level and many of them with steep sides.

In 1908–1909 no corrections were made for the water drawn from or added to storage. In 1910–1911 corrections were made for the water drawn from or added to storage in the Borden Brook Reservoir, but not in other ponds. No allowance is made for the invisible storage in the ground about the reservoir, and there is none as far as can be ascertained.

The drainage area is steep, rocky, and perhaps three fourths forested.

The elevation above the sea varies from 500 to 1 750 ft.

The discharge in 1910–1911, at times when all of the water was used for water supply purposes, was measured by a Venturi meter, and when wasting over the dam was measured also by weir on which accurate coefficients have been established by the Testing Station of Cornell University at Ithaca, N. Y.

The precipitation is measured by United States Geological Survey standard gage. Depth of snowfall is measured in several places; a sample collected of average depth and melted.

SPRINGFIELD, MASS., WATER WORKS, 1908

Yield of Westfield Little River. Total drainage area, 43 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	3 290	2.47	3.84	1.79	4.43	247.5
February	2 630	2.11	3.28	5.67	3.54	62.4
March	5 820	4.36	6.79	1.92	7.83	407.8
April	2 590	2.01	3.12	4.08	3.48	85.2
May	3 590	2.70	4.19	6.67	4.83	72.4
June	530	0.41	0.64	3.43	0.71	20.7
July	375	0.28	0.44	5.13	0.50	9.8
August	281	0.21	0.33	4.42	0.38	8.6
September	110	0.08	0.13	1.43	0.15	10.5
October	200	0.15	0.23	2.25	0.27	12.0
November	227	0.18	0.27	0.40	0.31	77.5
December	710	0.53	0.83	3.43	0.95	27.7
The Year	20 353	1.30	2.01	40.62	27.38	67.4

SPRINGFIELD, MASS., WATER WORKS, 1909.

Month.	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	1 590	1.20	1.85	4.67	2.13	45.6
February	4 140	3.45	5.35	5.42	5.57	102.8
March	3 730	2.80	4.35	3.40	5.02	147.6
April	4 980	3.86	6.00	6.67	6.69	100.3
May	2 070	1.56	2.42	2.87	2.79	97.3
June	564	0.44	0.68	2.30	0.76	33.1
July	158	0.12	0.18	2.15	0.21	9.8
August	265	0.20	0.31	5.54	0.36	6.5
September	181	0.14	0.22	4.08	0.24	5.9
October	202	0.15	0.24	1.16	0.27	23.3
November	222	0.17	0.27	2.37	0.30	12.7
December	935	0.70	1.09	4.64	1.26	27.2
The Year	19 037	1.23	1.91	45.27	25.30	55.8

SPRINGFIELD, MASS., WATER WORKS, 1910.

Total drainage area, 48 sq. miles.

Month.	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	2 990	2.01	3.12	3.22	3.60	112.0
February	2 910	2.17	3.37	4.90	3.51	71.6
March	5 040	3.39	5.25	0.80	6.05	756.0
April	2 480	1.72	2.66	4.37	2.97	68.0
May	936	0.63	0.98	4.10	1.13	27.6
June	1 800	1.25	1.94	3.88	2.16	55.9
July	246	0.17	0.26	0.42	0.30	71.5
August	245	0.17	0.26	4.83	0.30	6.2
September	158	0.11	0.17	2.99	0.19	6.4
October	34	0.02	0.03	0.96	0.03	3.1
November	757	0.53	0.82	6.25	0.92	14.7
December	309	0.21	0.33	2.62	0.38	14.5
The Year	17 905	1.03	1.60	39.34	21.54	54.8

SPRINGFIELD, MASS., WATER WORKS, 1911.

Month.	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	1 000	0.67	1.04	1.17	1.20	102.0
February	382	0.28	0.43	2.26	0.45	19.9
March	1 860	1.25	1.94	4.39	2.24	51.0
April	3 580	2.49	3.86	2.74	4.31	157.0
May	1 250	0.84	1.30	2.07	1.50	72.5
June	1 530	1.06	1.64	4.17	1.83	43.8
July	318	0.21	0.33	3.46	0.38	11.0
August	478	0.32	0.50	6.60	0.58	8.8
September	1 220	0.84	1.30	5.32	1.45	27.3
October	4 970	3.34	5.18	8.99	5.97	66.4
November	2 580	1.79	2.77	3.77	3.09	81.9
December	2 260	1.52	2.35	3.44	2.71	78.8
The Year	21 428	1.22	1.89	48.38	25.71	53.1

WESTFIELD, MASS., WATER WORKS.

Tillotson Brook.

Information furnished by John L. Hyde, town engineer.

The yield of Tillotson Brook is measured below the junction with Hollister Brook in Granville, Mass.

The records are for the years 1908–1911.

Drainage area, which includes practically no water surfaces or swamps, 5.84 sq. miles. A small intake reservoir has an area of only about one acre.

There is apparently no leakage into or out of the drainage area to affect the records.

The drainage area is about 80 per cent. forested. The soil is gravel and rocks, with very little loam.

The elevation above the sea ranges from about 550 to 1 500 ft., and averages about 990 ft.

The discharge measurements were made at a weir, and heights were read twice each day by the use of a hook gage.

Records of precipitation were obtained from a standard rain gage 8 in. in diameter, located near the gaging station. The snow is melted and water measured. Judging from experience elsewhere, the average precipitation on the drainage area would be greater than that recorded, because of the higher elevation of a portion of the area.

WESTFIELD WATER WORKS, 1908.

Yield of Tillotson Brook. Total drainage area (all land surface), 5.84 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January..	235.711	1.302	2.015	3.05	2.32	76.15
February.	272.669	1.610	2.491	5.82	2.69	46.16
March...	501.118	2.768	4.283	3.05	4.94	161.89
April....	291.007	1.661	2.570	3.26	2.87	87.96
May......	364.433	2.013	3.115	6.42	3.59	55.93
June.....	124.216	0.709	1.097	2.27	1.22	53.92
July.....	81.830	0.452	0.699	4.11	0.80	19.61
August...	85.269	0.471	0.729	5.02	0.84	16.73
September..	32.937	0.188	0.290	1.63	0.32	19.91
October.	53.044	0.293	0.453	3.02	0.52	17.30
November.	42.924	0.245	0.379	0.83	0.42	50.95
December	72.234	0.399	0.617	2.95	0.71	24.13
The Year.	2 157.395	1.009	1.561	41.43	21.24	51.26

WESTFIELD WATER WORKS, 1909.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	139.406	0.770	1.911	4.06	1.37	33.81
February	267.191	1.631	2.528	6.23	2.63	42.26
March	452.238	2.498	3.865	4.76	4.46	93.62
April	521.495	2.976	4.601	6.38	5.14	80.54
May	294.552	1.627	2.517	3.45	2.90	84.12
June	117.033	0.668	1.033	2.26	1.15	51.02
July	40.552	0.224	0.346	2.19	0.40	18.25
August	88.709	0.490	0.758	6.28	0.87	13.92
September	13.975	0.251	0.388	3.80	0.43	11.40
October	39.828	0.220	0.340	1.22	0.39	32.17
November	43.800	0.250	0.387	2.73	0.43	15.80
December	86.718	0.479	0.741	3.90	0.85	21.91
The Year	2 135.497	1.007	1.618	47.26	21.02	44.47

WESTFIELD WATER WORKS, 1910.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	275.724	1.523	2.356	6.40	2.72	12.45
Feburary	227.456	1.391	2.152	4.98	2.24	45.00
March	582.043	3.215	4.974	1.48	5.73	387.52
April	337.610	1.927	2.981	4.79	3.33	69.45
May	194.336	1.074	1.661	3.25	1.91	58.92
June	183.609	1.048	1.621	4.08	1.81	44.34
July	36.751	0.203	0.314	1.29	0.36	28.09
August	33.311	0.184	0.284	3.58	0.33	9.17
September	37.843	0.216	0.334	4.08	0.37	9.14
October	26.613	0.147	0.226	1.01	0.26	25.96
November	94.433	0.539	0.834	5.12	0.92	18.17
December	119.486	0.660	1.021	1.78	1.18	66.14
The Year	2 149.215	1.011	1.563	41.84	21.16	50.57

WESTFIELD WATER WORKS, 1911.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	69.198	0.383	0.593	2.06	0.68	33.09
February	64.590	0.395	0.611	2.09	0.64	30.45
March	278.983	1.511	2.384	3.31	2.75	83.05
April	299.767	1.711	2.647	2.55	2.95	115.83
May	83.096	0.459	0.710	1.15	0.82	71.20
June	101.090	0.577	0.892	4.01	1.00	24.84
July	26.613	0.147	0.227	4.40	0.25	5.73
August	64.631	0.357	0.552	6.94	0.61	9.17
September	91.554	0.522	0.807	4.95	0.90	18.22
October	326.777	1.805	2.793	10.10	3.22	31.88
November	187.639	1.701	1.657	3.00	1.85	61.63
December	261.603	1.445	2.236	3.44	2.58	74.93
The Year	1 855.541	0.868	1.342	48.00	18.28	38.08

WORCESTER, MASS., WATER WORKS.

Tatnuck Brook.

Information furnished by Frederick A. McClure, city engineer. The yield is measured at the lowest water-works dam, and the records cover the years 1908–February, 1912.

Drainage area, including water surfaces		5.231 sq. miles
Area of water surfaces	0.285	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 0.020 sq. miles of drained swamps .	0.006	
40 per cent. of 0.066 sq. miles of undrained swamps	0.026	
Total area reckoned as water surfaces		0.317 sq. miles
Area of land (upland) surface		4.914 sq. miles

Full corrections are made for the water drained from or added to storage except that no allowance is made for storage in the ground surrounding the reservoirs.

There is no appreciable leakage from the reservoirs, but beginning in August, 1911, some water was diverted into this area from

WORCESTER, MASS., WATER WORKS, 1908.

Yield of Tatnuck Brook. Total drainage area, 5.231 sq. miles. Area of land surface, 4.914 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	....	....	....	....		....	....	2.98	....	....	....	....
Feb.	....	....	....	....		....	....	5.01	....	....	....	....
Mar.	....	....	....	....	....	....	....	3.34	....	....	....	....
Apr.	....	....	....	....		....	....	2.10	....	....	....	....
May	....	....	....				....	4.33	....	....	....	....
June	86.3	−21.6	64.7	0.586	0.90	0.412	0.63	1.72	1.00	58.2	0.71	41
July	48.3	−6.0	42.3	0.317	0.48	0.261	0.40	4.91	0.55	11.2	0.46	9
Aug.	58.6	5.2	63.8	0.384	0.59	0.393	0.60	6.47	0.68	10.5	0.70	11
Sept.	25.4	−13.9	11.5	0.172	0.26	0.073	0.11	1.52	0.30	19.7	0.12	8
Oct.	36.2	−6.4	29.8	0.237	0.36	0.184	0.28	1.92	0.42	21.9	0.32	17
Nov.	43.3	−6.0	37.3	0.292	0.45	0.238	0.36	1.05	0.50	47.6	0.41	39
Dec.	60.7	8.8	69.5	0.330	0.51	0.429	0.66	3.34	0.59	17.7	0.76	23
Year	2 310.9	−3.3	2 307.6	1.277	1.90	1.205	1.86	38.99	26.87	68.9	25.38	65

WORCESTER, MASS., WATER WORKS, 1909.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	78.8	9.6	88.4	0.513	0.79	0.545	0.84	2.98	0.91	30.5	0.97	33
Feb.	398.5	27.1	425.6	2.882	4.46	2.996	4.49	6.36	4.64	73.6	4.68	73
Mar.	404.0	14.4	418.4	2.651	4.10	2.580	3.99	4.31	4.73	109.8	4.60	106
Apr.	534.3	19.9	554.2	3.630	5.61	3.531	5.46	6.48	6.26	96.6	6.09	94
May	249.9	−11.1	238.8	1.645	2.54	1.472	2.27	2.54	2.93	115.4	2.62	103
June	71.9	−15.3	56.6	0.489	0.75	0.361	0.55	2.84	0.84	29.6	0.62	22
July	20.9	−20.5	0.4	0.137	0.21	0.003	0.001	2.19	0.24	11.0	0.0049	0.2
Aug.	38.7	−10.8	27.9	0.253	0.39	0.172	0.26	3.39	0.45	13.3	0.30	9
Sept.	37.0	−0.9	36.1	0.249	0.38	0.230	0.35	3.94	0.42	10.7	0.39	10
Oct.	31.6	−6.3	25.3	0.205	0.31	0.156	0.24	1.75	0.36	20.6	0.27	16
Nov.	44.3	−0.9	43.4	0.296	0.45	0.277	0.42	2.04	0.50	24.5	0.47	23
Dec.	69.9	5.6	75.5	0.451	0.69	0.465	0.72	3.64	0.80	22.0	0.83	23
Year	1 979.8	10.8	1 990.6	1.098	1.70	1.043	1.61	42.46	23.08	54.4	22.20	52

WORCESTER, MASS., WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	303.8	19.7	323.5	1.962	3.03	1.995	3.078	5.77	3.49	60.5	3.55	61
Feb.	319.5	13.7	333.2	2.299	3.55	2.275	3.519	3.98	3.70	92.9	3.66	92
Mar.	475.9	−1.3	474.6	3.117	4.82	2.927	4.529	1.46	5.56	381.0	5.22	357
Apr	187.1	3.5	190.6	1.270	1.96	1.215	1.879	3.61	2.19	60.8	2.09	58
May	119.6	−14.9	104.7	0.785	1.21	0.646	0.999	1.75	1.39	79.4	1.15	66
June	139.8	−15.9	123.9	0.946	1.46	0.789	1.221	2.48	1.63	65.7	1.36	55
July	27.4	−20.4	7.0	0.179	0.27	0.043	0.066	1.82	0.31	17.0	0.07	4
Aug.	39.1	−4.9	34.2	0.254	0.39	0.211	0.326	4.39	0.45	10.3	0.37	8
Sept.	28.8	−3.8	25.0	0.192	0.29	0.159	0.246	3.19	0.32	10.0	0.27	8
Oct.	27.7	−6.7	21.0	0.179	0.27	0.154	0.200	1.29	0.31	24.0	0.23	17
Nov.	49.0	6.5	55.5	0.324	0.50	0.354	0.547	4.23	0.56	13.2	0.61	11
Dec.	73.9	3.4	77.3	0.472	0.73	0.477	0.737	2.66	0.84	31.6	0.85	32
Year	1 791.6	−21.1	1 770.5	0.988	1.52	0.927	1.445	36.63	20.75	56.6	19.47	53

WORCESTER, MASS., WATER WORKS, 1911.

Jan.	149.6	6.1	155.7	0.953	1.17	0.960	1.485	3.03	1.70	56.1	1.71	56
Feb.	113.9	3.6	117.5	0.774	1.19	0.803	1.242	2.38	1.24	52.1	1.29	54
Mar.	257.5	7.2	264.7	1.642	2.54	1.633	2.526	4.09	2.93	71.6	2.91	71
Apr.	316.0	−2.4	313.6	2.096	3.24	1.998	3.092	2.29	3.62	158.0	3.45	150
May	132.2	−9.0	123.2	0.851	1.31	0.760	1.175	2.06	1.51	73.3	1.35	65
June	87.3	−10.9	76.4	0.578	0.89	0.487	0.752	2.35	0.99	42.1	0.84	36
July	42.1	−7.4	34.7	0.268	0.41	0.214	0.331	3.23	0.47	11.6	0.38	12
Aug.	38.7	−0.2	38.5	0.245	0.38	0.237	0.367	5.40	0.44	8.2	0.42	7
Sept.	50.2	0	50.2	0.328	0.50	0.320	0.495	4.11	0.56	13.6	0.55	13
Oct.	163.7	6.6	170.3	1.041	1.61	1.050	1.624	5.53	1.85	33.5	1.87	33
Nov.	212.8	9.2	222.0	1.417	2.19	1.414	2.188	4.60	2.44	53.0	2.44	53
Dec.	213.3	7.4	220.7	1.384	2.14	1.361	2.106	3.17	2.47	77.9	2.43	76
Year	1 777.3	10.2	1 787.5	0.964	1.49	0.936	1.448	42.21	20.22	47.9	19.66	46

WORCESTER, MASS., WATER WORKS, 1912.

Jan.	150.8	6.0	156.8	0.977	1.51	0.967	1.49	2.34	1.74	71.4	1.72	73
Feb.	119.6	7.1	156.7	1.074	1.66	1.033	1.59	2.67	1.79	67.0	1.72	64

a portion of the Wachusett drainage area, and due allowance has been made in the computations therefor.

The drainage area consists of rugged hills and steep slopes with clayey subsoil and stony fields with small area of gravel deposits. From 50 to 60 per cent. of the area is forested, as near as can be estimated.

The elevation above the sea ranges from 720 to 1 400 ft. and averages about 950 ft.

The precipitation is measured by an 8-in standard gage near the lowest reservoir dam.

PAWTUCKET, R. I., WATER WORKS.

Abbott Run.

Information furnished by George A. Carpenter, city engineer.

The records presented give the yield of Abbott Run at Cumberland Mills, R. I., for the years 1908–1912.

Drainage area, including water surfaces	26.94 sq. miles
Area of water surfaces	0.75 sq. miles
Area of land surface	26.19 sq. miles

There are no swampy areas of any material size.

Corrections are made for the water drawn from or added to storage in the reservoir, which has an area of 0.58 sq. miles. There is no percolation or leakage or diversion of water to materially affect the records.

The drainage area is covered with small farms, fertile valleys, and somewhat steep hillsides. Outcroppings of ledge occur in many locations. The area is not heavily wooded.

The elevation above the sea varies from 48 to from 300 to 400 ft., and averages about 150 ft.

The discharge is measured over a steel crested weir 54.92 ft. long, and the run-off computed by the Francis weir formula.

The precipitation is collected in a rain gage 14.853 in. in diameter and weighed, each ounce in weight being equal to 0.01 in. in depth. Snowfall is melted and weighed.

PAWTUCKET, R. I., WATER WORKS, 1908.

Yield of Abbott Run. Total drainage area, 26.94 sq. miles. Area of land surface, 26.19 sq. miles

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 635.7	41.4	1 677.1	2.015	3.117	2.008	3.107	4.14	3.59	86.8	3.58	86.5
Feb.	1 872.7	54.3	1 927.0	2.554	3.951	2.555	3.953	5.22	4.12	79.0	4.12	78.9
Mar.	1 892.9	33.8	1 926.7	2.331	3.607	2.307	3.569	4.30	4.16	96.9	4.11	95.6
Apr.	985.0	−8.3	976.7	1.254	1.910	1.209	1.870	2.33	2.16	92.8	2.09	89.7
May	940.7	14.8	955.5	1.159	1.793	1.144	1.770	5.60	2.06	36.8	2.04	36.4
June	547.1	−53.4	493.7	0.696	1.077	0.611	0.945	1.44	1.20	83.5	1.05	72.9
July	381.3	14.3	395.6	0.470	0.726	0.474	0.733	7.08	0.84	11.9	0.84	11.9
Aug.	277.1	−12.2	264.9	0.341	0.528	0.317	0.491	4.56	0.61	13.4	0.57	12.5
Sept.	155.2	−41.5	113.7	0.197	0.306	0.141	0.218	0.93	0.34	36.6	0.24	25.8
Oct.	148.5	4.7	153.2	0.183	0.283	0.183	0.284	3.52	0.33	9.4	0.33	9.4
Nov.	198.3	−18.0	180.3	0.252	0.391	0.223	0.345	0.87	0.44	50.5	0.39	44.8
Dec.	420.2	16.5	436.7	0.518	0.801	0.523	0.809	2.78	0.92	33.1	0.93	33.5
Year	9 454.7	46.4	9 501.1	0.986	1.530	0.964	1.495	42.77	20.77	48.6	20.29	47.4

PAWTUCKET, R. I., WATER WORKS, 1909.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	482.9	27.4	510.3	0.595	0.920	0.611	0.945	3.07	1.06	34.6	1.09	35.5
Feb.	1 878.3	67.7	1 946.0	2.561	3.963	2.580	3.992	6.25	4.12	66.0	4.17	66.7
Mar.	1 585.7	26.4	1 612.1	1.953	3.022	1.930	2.987	3.73	3.48	93.4	3.44	92.2
Apr.	1 451.7	30.8	1 482.5	1.848	2.859	1.835	2.838	5.34	3.19	59.8	3.17	59.4
May	1 145.9	−35.9	1 110.0	1.411	2.184	1.329	2.056	1.70	2.52	148.2	2.37	139.4
June	438.4	−38.3	400.1	0.558	0.863	0.495	0.766	2.60	0.96	36.9	0.85	32.7
July	154.1	−54.4	99.7	0.190	0.294	0.119	0.185	1.80	0.34	18.9	0.21	11.7
Aug.	110.5	−45.4	65.1	0.136	0.211	0.078	0.121	2.01	0.24	11.9	0.14	7.0
Sept.	95.4	2.5	97.9	0.121	0.188	0.121	0.187	4.31	0.21	4.9	0.21	4.9
Oct.	136.0	−24.7	111.3	0.168	0.259	0.133	0.206	1.26	0.30	23.8	0.24	19.0
Nov.	213.2	19.8	233.0	0.271	0.420	0.288	0.446	3.77	0.47	12.5	0.50	13.3
Dec.	280.3	39.6	319.9	0.345	0.534	0.383	0.593	1.55	0.62	13.6	0.68	14.9
Year	7 972.4	15.5	7 987.9	0.834	1.291	0.812	1.257	40.39	17.51	43.5	17.06	42.2
PAWTUCKET, R. I., WATER WORKS, 1910.												
Jan.	1 388.8	51.0	1 439.8	1.711	2.647	1.724	2.668	4.88	3.05	62.5	3.08	63.1
Feb.	1 474.2	30.3	1 504.5	2.010	3.111	1.995	3.086	3.38	3.24	96.0	3.21	95.0
Mar.	1 544.3	1.6	1 545.9	1.902	2.943	1.851	2.864	1.82	3.40	187.0	3.30	181.3
Apr.	470.7	−13.0	457.7	0.599	0.927	0.566	0.876	1.97	1.03	52.4	0.98	49.7
May	396.8	−30.0	366.8	0.489	0.756	0.439	0.680	2.16	0.87	40.3	0.78	36.1
June	447.5	−29.9	417.6	0.570	0.881	0.517	0.799	3.21	0.98	30.2	0.89	27.5
July	106.4	−62.2	44.2	0.131	0.203	0.053	0.082	1.20	0.23	19.2	0.09	7.5
Aug.	105.3	−45.3	60.0	0.130	0.201	0.072	0.111	2.02	0.23	11.4	0.14	6.9
Sept.	130.2	−32.8	97.4	0.166	0.256	0.120	0.186	1.60	0.29	18.1	0.21	13.1
Oct.	44.0	−24.7	19.3	0.054	0.084	0.023	0.036	1.26	0.10	8.0	0.04	3.2
Nov.	68.8	35.0	103.8	0.088	0.136	0.128	0.199	4.91	0.15	3.0	0.22	4.5
Dec.	221.0	10.4	231.4	0.272	0.421	0.277	0.429	2.31	0.48	20.8	0.49	21.2
Year	6 398.0	−109.6	6 288.4	0.669	1.036	0.640	0.989	30.78	14.05	45.7	13.43	43.7
PAWTUCKET, R. I., WATER WORKS, 1911.												
Jan.	452.7	27.1	479.8	0.558	0.863	0.575	0.889	3.04	1.00	32.9	1.03	33.9
Feb.	517.5	17.4	534.9	0.706	1.092	0.709	1.097	2.39	1.14	47.7	1.14	47.7
Mar.	817.8	25.1	842.9	1.007	1.559	1.009	1.562	3.63	1.80	49.6	1.80	49.6
Apr.	1 295.1	7.0	1 302.1	1.648	2.551	1.611	2.493	3.51	2.85	81.3	2.78	79.2
May	499.1	−32.3	466.8	0.615	0.951	0.559	0.865	1.98	1.10	55.6	1.00	50.5
June	328.9	−41.1	287.8	0.419	0.648	0.356	0.551	2.38	0.72	30.3	0.62	26.1
July	145.7	−29.0	116.7	0.179	0.278	0.140	0.216	3.75	0.32	8.5	0.25	6.7
Aug.	161.0	18.5	179.5	0.198	0.307	0.215	0.332	6.92	0.35	5.1	0.38	5.5
Sept.	360.8	−19.9	340.9	0.459	0.711	0.422	0.653	2.59	0.79	30.5	0.73	28.2
Oct.	416.3	−2.2	414.1	0.513	0.793	0.496	0.767	2.99	0.91	30.4	0.88	29.4
Nov.	902.5	51.4	953.9	1.149	1.777	1.180	1.826	6.20	1.98	32.3	2.04	32.9
Dec.	1 228.8	27.2	1 256.0	1.514	2.342	1.504	2.327	3.60	2.70	75.1	2.68	74.4
Year	7 126.2	49.2	7 175.4	0.746	1.154	0.730	1.129	42.98	15.66	36.5	15.33	35.7
PAWTUCKET, R. I., WATER WORKS, 1912. Total drainage area, 26.94 sq. miles. Area of land surface, 26.21 sq. miles.												
Jan.	874.6	32.2	906.8	1.076	1.665	1.086	1.680	3.49	1.92	55.0	1.94	55.6
Feb.	1 098.3	22.6	1 120.9	1.445	2.236	1.435	2.220	2.82	2.41	85.5	2.39	84.8
Mar.	2 298.2	78.7	2 376.9	2.829	4.376	2.846	4.404	7.87	5.04	64.1	5.08	64.6
Apr.	1 691.2	14.6	1 705.8	2.151	3.328	2.111	3.265	4.12	3.72	90.3	3.64	88.3
May	1 344.5	−2.8	1 341.7	1.655	2.560	1.606	2.486	4.24	2.95	69.6	2.87	67.7
June	402.3	−62.4	339.9	0.512	0.792	0.421	0.651	0.65	0.88	135.2	0.73	112.3
July	157.0	−35.9	121.1	0.193	0.299	0.145	0.224	3.16	0.34	10.8	0.26	8.2
Aug.	150.2	−24.5	125.7	0.185	0.286	0.150	0.233	3.58	0.33	9.2	0.27	7.5
Sept.	93.7	−28.9	64.8	0.119	0.185	0.080	0.124	1.85	0.21	11.4	0.14	7.6
Oct.	160.6	4.2	164.8	0.198	0.306	0.197	0.305	3.49	0.35	10.0	0.35	10.0
Nov.	255.0	14.3	269.3	0.324	0.502	0.333	0.516	3.37	0.56	16.6	0.57	16.9
Dec.	591.4	58.4	649.8	0.728	1.126	0.778	1.204	6.09	1.30	21.3	1.39	22.8
Year	9 117.0	70.5	9 187.5	0.950	1.471	0.932	1.442	44.73	20.01	44.7	19.63	43.9

HARTFORD, CONN., WATER WORKS.

Information furnished by Caleb Mills Saville, chief engineer.

The records present the combined yield of a number of small streams on the easterly slope of Talcott Mountain at West Hartford, Conn., for the period from June, 1909, to the end of 1912. These streams flow into reservoirs, which in turn discharge into Reservoir No. 1, from which the supply of the city of Hartford is taken.

Drainage area, including water surfaces		11.92 sq. miles
Area of water surfaces	0.70	
30 per cent. of 0.5 sq. miles of undrained swamps . .	0.15	
Total area reckoned as water surface		0.85 sq. miles
Area of land (upland) surface		11.07 sq. miles

HARTFORD, CONN., WATER WORKS, 1909.

Yield of Hartford Reservoirs. Total drainage area, 11.92 sq. miles. Area of land surface, 11.07 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.		....	....	....	....	....	....	....	....	....	....	....
Feb.	....	....	....	....	....	....	....	....	....	....	....	....
Mar.	....	....	....	....	....	....	....	....	....	....	....	....
Apr.	....	....	....	....	....	....	....	....	....	....	....	....
May	....	....	....	....	....	....	....	....	....	....	....	....
June	117.6	−40.6	77	0.354	0.548	0.22	0.34	2.78	0.61	21.9	0.37	13
July	7.5	−56.5	−49	0.022	0.034	−0.13	−0.20	1.92	0.04	2.8	−0.24	−12
Aug.	50.6	−21.6	29	0.148	0.229	0.08	0.12	3.82	0.26	6.8	0.14	4
Sept.	48.9	−5.9	43	0.147	0.227	0.12	0.19	3.62	0.25	6.9	0.21	6
Oct.	45.1	−16.1	29	0.131	0.203	0.08	0.12	1.66	0.24	14.5	0.14	8
Nov.	56.2	0.8	57	0.169	0.262	0.16	0.25	2.33	0.29	12.4	0.28	12
Dec.	181.8	14.2	196	0.530	0.820	0.53	0.82	3.15	0.95	30.1	0.95	30
Year	507.7	−125.7	382.0	0.214	0.331	0.15	0.23	19.28	2.64	13.7	1.85	9.6

HARTFORD, CONN., WATER WORKS, 1910.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day (Land).	Cu. Ft. per Sec. (Land).	Mil. Gal. per Day (Total).	Cu. Ft. per Sec. (Total).	Precipitation Inches.	Land Inches.	Land Per Cent.	Total Inches.	Total Per Cent.
Jan.	908.7	58.0	966.7	2.60	4.02	2.62	4.06	6.12	4.72	77.1	4.67	76
Feb.	662.6	35.8	698.4	2.11	3.27	2.09	3.24	3.81	3.44	90.3	3.37	88
Mar.	812.9	−6.8	806.1	2.36	3.65	2.18	3.38	1.22	4.23	347.0	3.99	327
Apr.	474.5	15.8	490.3	1.42	2.20	1.37	2.12	4.10	2.47	60.2	2.37	58
May	220.6	−26.4	194.2	0.64	0.99	0.52	0.80	2.57	1.15	44.8	0.94	37
June	262.9	−22.6	240.3	0.79	1.22	0.67	1.04	3.92	1.37	34.9	1.16	30
July	47.8	−47.4	0.4	0.14	0.21	0.00	0.00	2.49	0.25	10.0	0.00	0
Aug.	34.3	−39.1	−4.8	0.10	0.15	−0.01	−0.02	2.52	0.18	7.1	−0.02	−1
Sept.	33.7	−12.3	21.4	0.10	0.15	0.06	0.09	3.14	0.17	5.4	0.10	3
Oct.	19.4	−27.5	−8.1	0.06	0.09	−0.02	−0.03	0.88	0.10	11.4	−0.04	−5
Nov.	79.7	27.7	107.4	0.24	0.37	0.30	0.46	4.65	0.41	8.8	0.52	11
Dec.	132.5	1.7	134.2	0.38	0.59	0.36	0.56	1.66	0.69	41.6	0.65	39
Year	3 689.6	−43.1	3 646.5	0.91	1.40	0.84	1.30	37.08	19.18	51.7	17.83	48

HARTFORD, CONN., WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	236.7	18.2	254.9	0.68	1.05	0.69	1.07	2.61	1.23	47.1	1.23	17
Feb.	227.8	14.5	242.3	0.72	1.12	0.72	1.12	2.36	1.18	50.0	1.17	50
Mar.	736.0	23.4	759.4	2.11	3.26	2.06	3.18	3.75	3.82	101.9	3.67	98
Apr.	744.7	−0.1	744.6	2.23	3.45	2.08	3.22	2.96	3.87	130.8	3.60	122
May	118.2	−38.0	80.2	0.34	0.53	0.22	0.34	1.65	0.61	37.0	0.39	24
June	111.3	−40.2	71.1	0.33	0.51	0.20	0.31	2.48	0.58	23.4	0.34	14
July	36.3	−40.2	−3.9	0.10	0.16	−0.01	−0.02	2.81	0.19	6.8	−0.02	−1
Aug.	57.4	6.8	64.2	0.16	0.26	0.17	0.27	6.06	0.30	5.0	0.31	5
Sept.	88.2	−21.2	67.0	0.26	0.40	0.19	0.29	2.24	0.46	20.5	0.32	14
Oct.	882.8	77.5	960.3	2.53	3.92	2.60	4.02	9.83	4.59	46.7	4.64	47
Nov.	596.0	25.4	621.4	1.78	2.76	1.74	2.69	4.17	3.10	74.4	3.00	72
Dec.	478.4	23.2	501.6	1.38	2.14	1.36	2.10	3.19	2.49	78.0	2.42	76
Year	4 313.8	49.3	4 363.1	1.05	1.63	1.00	1.55	44.11	22.42	50.8	21.07	48

HARTFORD, CONN., WATER WORKS, 1912.

Jan.	99.0	9.4	108.4	0.29	0.45	0.29	0.45	1.63	0.51	31.3	0.52	32
Feb.	374.0	25.2	399.2	1.16	1.80	1.16	1.79	2.89	1.95	67.5	1.93	67
Mar.	1 049.7	63.3	1 113.0	3.04	4.71	3.02	4.66	6.17	5.45	88.3	5.37	87
Apr.	534.2	15.6	549.8	1.60	2.48	1.54	2.38	4.07	2.78	68.3	2.66	65
May	745.8	9.0	754.8	2.17	3.36	2.02	3.13	5.10	3.88	76.1	3.62	71
June	57.1	−70.0	−12.9	0.17	0.26	−0.04	−0.06	0.51	0.30	58.8	−0.06	−12
July	33.7	−51.0	−17.3	0.10	0.15	−0.05	−0.07	2.12	0.18	8.5	−0.08	−4
Aug.	27.8	−30.3	−2.5	0.08	0.12	−0.01	−0.01	3.08	0.14	4.5	−0.01	−0.4
Sept.	25.2	−22.7	2.5	0.07	0.12	0.01	0.01	2.21	0.13	5.9	0.01	0.5
Oct.	44.2	−13.6	30.6	0.13	0.20	0.08	0.13	1.92	0.23	12.0	0.15	8
Nov.	97.8	18.0	115.8	0.29	0.44	0.32	0.50	4.04	0.50	12.4	0.56	11
Dec.	322.9	25.0	347.9	0.91	1.41	0.94	1.46	4.29	1.68	39.1	1.68	39
Year	3 411.4	−22.1	3 389.3	0.83	1.29	0.78	1.20	38.03	17.73	46.6	16.35	43

Full corrections are made for the water drained from or added to storage, except that no allowance is made for the storage in the ground surrounding the reservoirs. It is estimated that the total leakage from the reservoirs when they are full is about 200 000 gal. daily, and due allowance is made therefor in the computations.

The drainage area has steep slopes. The soil is of a reddish clayey nature and somewhat impervious. It is estimated that about 70 per cent. of the area is forested and uninhabited, the remainder being open farming and pasture land.

The elevation above the sea ranges from 260 to 950 ft., and averages about 460 ft.

The water consumed by the city is measured by a Venturi meter at Reservoir No. 1. The water wasted is measured by a standard weir, and the leakage is also measured by weirs.

The precipitation is measured at three well-distributed places on the drainage area, with United States Weather Bureau standard 8-in. gages. The snowfall in the rain gages is melted and measured.

NORWICH, CONN., WATER WORKS.

Fairview and Meadow Brooks.

Information furnished by C. E. Chandler, civil engineer.

The yield of the Fairview and Meadow brooks is measured at the Fairview Reservoir and the records cover the years 1910–1912.

Drainage area, including water surfaces		2.300 sq. miles
Area of water surfaces	0.125	
40 per cent. of 0.117 sq. miles of undrained swamps,	0.047	
Total area reckoned as water surfaces		0.172 sq. miles
Area of land (upland) surface		2.128 sq. miles

Full corrections are made for the water drained from or added to storage, but no allowance is made for a moderate amount of ground water storage. There is probably no percolation or leakage to materially affect the records of run-off.

NORWICH, CONN., WATER WORKS, 1910.

Yield of Fairview and Meadow brooks. Total drainage area, 2.3 sq. miles. Area of land surface, 2.128 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. Per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	125	12	137	1.902	2.945	1.921	2.972	4.70	3.38	72	3.43	73
Feb.	127	8	135	2.170	3.364	2.096	3.242	3.64	3.43	94	3.38	93
Mar.	120	−3	117	1.870	2.898	1.640	2.538	0.84	3.24	386	2.93	349
Apr.	59	−2	57	0.950	1.473	0.826	1.277	2.47	1.60	65	1.43	58
May	51	−9	42	0.794	1.225	0.588	0.910	2.17	1.38	64	1.05	48
June	34	−10	24	0.547	0.837	0.347	0.537	2.81	0.92	33	0.60	21
July	9	−12	−3	0.140	0.217	−0.042	−0.065	2.90	0.24	8	−0.08	−3
Aug.	5	0	5	0.077	0.119	0.070	0.108	4.34	0.14	3	0.13	3
Sept.	9	−7	2	0.142	0.217	0.028	0.044	1.73	0.24	14	0.05	3
Oct.	8	−4	4	0.125	0.194	0.056	0.086	1.73	0.22	13	0.10	6
Nov.	11	3	14	0.168	0.264	0.202	0.316	3.44	0.30	9	0.35	10
Dec.	19	1	20	0.281	0.434	0.280	0.433	2.15	0.51	24	0.50	23
Year	577	−23	554	0.764	1.182	0.668	1.033	32.92	15.60	47	13.87	42

NORWICH, CONN., WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	42	12	54	0.639	0.975	0.738	1.143	3.82	1.14	30	1.35	35
Feb.	53	3	56	0.890	1.380	0.839	1.298	2.20	1.43	65	1.40	64
Mar.	90	6	96	1.350	2.093	1.346	2.082	3.72	2.43	65	2.40	65
Apr.	114	0	114	1.809	2.804	1.652	2.555	3.10	3.09	100	2.85	92
May	33	−13	20	0.522	0.869	0.280	0.433	0.69	0.89	129	0.50	72
June	21	−12	9	0.333	0.516	0.130	0.201	2.00	0.57	28	0.23	12
July	1	−13	−12	0.015	0.023	−0.168	−0.260	2.05	0.03	9	−0.30	−15
Aug.	4	−4	0	0.061	0.094	0.000	0.000	4.33	0.11	3	0.00	0
Sept.	12	−6	6	0.188	0.291	0.086	0.134	2.07	0.32	15	0.15	7
Oct.	16	0	16	0.243	0.377	0.224	0.346	3.11	0.43	14	0.40	13
Nov.	57	14	71	0.896	1.390	1.028	1.591	6.73	1.54	23	1.78	26
Dec.	99	4	103	1.520	2.356	1.444	2.234	2.68	2.68	100	2.58	96
Year	542	−9	533	0.706	1.097	0.633	0.982	36.50	14.66	40	13.34	37

NORWICH, CONN., WATER WORKS, 1912.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	61	4	65	0.912	1.411	0.912	1.411	2.43	1.65	68	1.63	67
Feb.	66	3	69	1.055	1.632	1.034	1.600	2.40	1.78	74	1.73	72
Mar.	209	17	226	3.138	4.854	3.170	4.904	8.06	5.65	70	5.65	70
Apr.	148	4	152	2.318	3.586	2.200	3.403	4.33	4.00	92	3.81	88
May	193	0	193	2.925	4.525	2.707	4.188	4.49	5.22	116	4.83	108
June	22	−14	8	0.341	0.532	0.116	0.179	0.60	0.60	100	0.20	33
July	0	−3	−3	0.000	0.000	−0.042	−0.065	5.44	0.00	0	−0.08	−1.5
Aug.	8	−7	1	0.120	0.186	0.014	0.021	2.75	0.22	8	0.03	1.1
Sept.	4	−4	0	0.062	0.096	0.000	0.000	2.56	0.11	4	0.00	0
Oct.	1	−4	−3	0.015	0.023	−0.042	−0.065	1.39	0.03	2	−0.08	6
Nov.	27	3	30	0.331	0.512	0.435	0.673	3.82	0.73	19	0.75	20
Dec.	56	10	66	0.782	1.210	0.925	1.431	6.74	1.51	22	1.65	24
Year	795	9	804	1.000	1.547	0.952	1.473	45.01	21.50	48	20.12	45

The drainage area is hilly, but the hills are not steep; there is very little forested and the soil is of an average character.

The elevation above the sea ranges from 260 to 480, and averages about 300 ft.

The water is measured through a Venturi meter, but for various reasons there may be inaccuracies in the records as great as 15 per cent.

The precipitation is measured by an old-fashioned rain gage located on the roof of City Hall, three miles from the drainage area. The water is poured into a graduated glass for measurements. Twelve inches of snow are counted as one inch of rain.

WATERBURY, CONN., WATER WORKS.

Wigwam Reservoir.

Information furnished by R. A. Cairns, city engineer.

The records presented give the yield of the west branch of the Naugatuck River at the Wigwam Dam for the years 1908–1912 inclusive.

Drainage area, including water surfaces		18.00 sq. miles
Area of water surfaces	0.180	
30 per cent. of 0.023 sq. miles of drained swamps .	0.007	
40 per cent. of 0.039 sq. miles of undrained swamps,	0.016	
Total area reckoned as water surfaces		0.20 sq. miles
Area of land (upland) surface		17.80 sq. miles

Full corrections are made for the water drained from or added to storage. There is very little storage in the ground surrounding the reservoirs, and no allowance is made for it. There is practically no leakage.

It is estimated that about two thirds of the drainage area is forested. The soil is generally impervious.

The elevation above the sea varies from 500 to 1 100 ft., and averages about 890 ft.

WATERBURY, CONN., WATER WORKS, 1908.

Yield of west branch of Naugatuck River. Total drainage area, 18 sq. miles. Area of land surface, 17.80 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 119.2	11.3	1 130.5	2.028	3.139	2.028	3.137	4.22	3.62	85.8	3.618	86
Feb.	1 182.4	16.2	1 198.6	2.291	3.549	2.297	3.553	5.71	3.82	66.9	3.832	67
Mar.	1 124.5	4.2	1 128.7	2.038	3.153	2.022	3.131	2.92	3.63	124.4	3.608	124
Apr.	559.2	−1.7	557.5	1.047	1.621	1.032	1.598	2.48	1.81	73.0	1.782	72
May	644.4	7.1	651.5	1.168	1.808	1.167	1.808	6.53	2.08	31.8	2.082	32
June	181.9	−15.0	166.9	0.341	0.528	0.309	0.478	1.22	0.59	48.4	0.534	44
July	65.6	−4.7	60.9	0.119	0.184	0.109	0.169	4.49	0.21	4.7	0.195	4
Aug.	64.4	−2.8	61.6	0.118	0.183	0.110	0.170	4.47	0.21	4.7	0.197	4
Sept.	24.0	−4.3	19.7	0.045	0.070	0.036	0.056	2.04	0.08	3.9	0.063	3
Oct.	52.0	−1.7	50.3	0.094	0.146	0.090	0.139	2.05	0.17	8.3	0.161	8
Nov.	60.5	−1.7	58.8	0.113	0.175	0.109	0.169	0.97	0.19	19.6	0.188	19
Dec.	156.6	2.4	159.0	0.284	0.440	0.285	0.441	3.31	0.51	15.4	0.508	15
Year	5 234.7	9.3	5 214.0	0.804	1.245	0.796	1.232	40.41	16.92	41.86	16.768	41

WATERBURY, CONN., WATER WORKS, 1909.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	534.3	6.1	540.4	0.969	1.500	0.969	1.501	3.84	1.73	45.0	1.727	15
Feb.	1 413.6	16.9	1 430.5	2.835	4.389	2.839	4.393	6.43	4.57	71.1	4.575	71
Mar.	1 270.3	11 1	1 281.4	2.302	3.565	2.297	3 551	4.91	4.11	83.7	4.096	83
Apr.	2 059.8	19.3	2 079.1	3.854	5.969	3.848	5.958	8.51	6.65	78.1	6.615	78
May	801.0	−4.9	799.1	1.457	2.255	1.432	2 218	3.08	2.60	84.4	2.555	83
June	158.6	−10.1	148.5	0.297	0.460	0.275	0.426	2.62	0.51	19.5	0.475	18
July	28.7	−12.5	16.2	0.052	0.081	0.029	0.045	1.99	0.09	4.5	0.052	3
Aug.	48.7	−4.5	44.2	0.088	0.136	0.079	0.122	3.88	0.16	4.1	0.141	4
Sept.	40.8	−1.0	39.8	0.076	0.118	0.074	0.115	3.72	0.13	3.5	0.127	3
Oct.	43.4	−3.3	40.1	0.079	0.122	0.072	0.111	1.34	0.14	10.5	0.128	10
Nov.	82.3	−1.0	81.3	0.154	0.238	0.151	0.234	1.57	0.27	17.2	0.260	17
Dec.	284.2	5.4	289.6	0.515	0.797	0.519	0.804	4.93	0.92	18.7	0.926	19
Year	6 768.7	21.5	6 790.2	1.042	1.614	1.033	1.599	46.82	21.88	46.7	21.707	46

WATERBURY, CONN., WATER WORKS, 1910.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 551.2	14.6	1 565.8	2.821	4.369	2.805	4.342	6 94	5.01	72.2	5.008	72
Feb.	958.7	9.9	968.6	1.924	2.978	1.922	2.975	4.24	3.10	73.1	3.098	73
Mar.	1 753.4	−1.7	1 751.7	3.177	4.919	3.139	4.856	1.19	5.67	476.4	5.600	471
Apr.	695.3	3.8	699.1	1.302	2.017	1.295	2.002	4 07	2.25	55.3	2.235	55
May	564.0	−2.1	561.9	1.022	1.583	1.006	1.557	3.85	1.83	47.5	1.796	47
June	674.9	−7.0	667.9	1.264	1.957	1.236	1.912	3.53	2.18	61.8	2.104	60
July	60.2	−9.6	50.6	0.109	0.169	0.091	0.141	3.09	0.19	6.2	0.162	5
Aug.	92.9	−6.3	86.6	0.168	0.260	0.155	0.240	3.59	0.30	8.4	0.277	8
Sept.	41.7	−4.2	37.5	0.078	0.121	0.070	0.108	2.52	0.14	5.6	0.120	5
Oct.	22.8	−5.2	17.6	0.041	0.063	0.032	0 050	0 61	0.07	10.9	0.056	9
Nov.	241.3	4.0	245.3	0.452	0.700	0 155	0.704	4.46	0.78	17.5	0.784	18
Dec.	272.7	1.6	274.3	0.491	0.764	0.492	0.761	2.26	0.88	38.9	0.878	39
Year	6 929.1	−2.2	6 926.9	1.067	1.652	1.055	1.634	40.38	22.40	55.5	22.118	55

WATERBURY, CONN., WATER WORKS, 1911.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	501.3	4.5	505.8	0.908	1.405	0.906	1.402	2.58	1.62	62.8	1.616	63
Feb.	372.8	5.0	377.8	0 748	1.158	0.749	1.160	2.52	1.21	48.0	1.208	48
Mar.	940.1	9.6	949.7	1.706	2.641	1.702	2.634	4.47	3.04	68.0	3.037	68
Apr.	1 013.2	−0.9	1 012.3	1.897	2.938	1.875	2.902	2.72	3.27	120.3	3.238	119
May	219.8	−12.5	207.3	0.398	0.616	0.372	0.576	0.87	0.71	81.6	0.663	76
June	152.0	−9.2	142.8	0.285	0.441	0.264	0.409	2 89	0.49	17.0	0.457	16
July	58.3	−6.1	52.2	0.106	0.164	0.094	0.146	4.16	0.19	4.6	0.167	4
Aug.	98.2	1.7	99.9	0.178	0.275	0.179	0.277	6.08	0.32	5.3	0.319	5
Sept.	229.0	−2.4	226.6	0.429	0.664	0.420	0.650	3.32	0.74	22.3	0.724	22
Oct.	1 705.3	16.0	1 721.3	3.092	4.788	3.085	4.776	8.00	5.51	68.9	5.502	69
Nov.	1 020.0	6.4	1 026.4	1.911	2.959	1.901	2.943	4.11	3.30	80.3	3.281	80
Dec.	721.6	5.0	726.6	1.307	2.023	1.303	2 018	2.97	2.33	78.4	2.322	78
Year	7 031.6	17.1	7 048.7	1.082	1.676	1.072	1.660	44 69	22.73	50.9	22.534	50.5

WATERBURY, CONN., WATER WORKS, 1912.

Month.	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Inches.	Per Cent.	Inches.	Per Cent.
Jan.	319.6	3.3	322.9	0.579	0.896	0.579	0.896	1.91	1.03	53.9	1.032	54
Feb.	749.9	6.8	756.7	1.451	2.247	1.450	2.243	3.02	2.42	80.1	2.420	80
Mar.	2 093.1	18.2	2 111.3	3.798	5.875	3.785	5.859	6.95	6.77	97.4	6.750	97
Apr.	1 065.4	3.0	1 068.4	1.995	3.088	1.979	3.062	3.80	3.44	90.6	3.416	90
May	980.6	−0.9	979.7	1.778	2.752	1.755	2.717	4.21	3.17	75.2	3.131	74
June	100.7	−15.3	85.4	0.189	0.292	0.158	0.245	1.12	0.33	29.5	0.273	24
July	19.9	−11.8	8.1	0.036	0.056	0.014	0.022	2.40	0.06	2.5	0.026	1
Aug.	29.9	−7.0	22.9	0.054	0.084	0.041	0.063	2.98	0.10	3.4	0.073	2
Sept.	21.2	−5.2	16.0	0.040	0.062	0.030	0.046	1.64	0.07	4.3	0.051	3
Oct.	100.4	1.2	101.6	0.182	0.282	0.182	0.282	3.88	0.32	8.2	0.325	8
Nov.	353.6	4.7	358.3	0.662	1.025	0.664	1.027	4.50	1.14	25.3	1.145	27
Dec.	610.5	9.7	620.2	1.107	1.714	1.112	1.721	4.60	1.97	42.8	1.983	43
Year	6 444.8	6.7	6 451.5	0.990	1.532	0.979	1.515	41.01	20.82	50.8	20.625	50.3

The water wasted from the reservoir is generally measured over the spillway, for which a coefficient has been determined by tests made by building a standard weir downstream. Occasional use is made of blow-off pipes, and the discharge from these is approximated. The water drawn for consumption is measured through a Venturi meter. During the years under consideration, the amount wasted was about twice as great as the amount drawn for consumption.

The precipitation is measured by two gages, one a Friez tipping-bucket recording gage, checked by stick measurement, and the other, located a mile distant, a non-recording Friez gage with stick measurement. The snowfall is determined in accordance with United States Weather Bureau instructions.

NEW YORK WATER SUPPLY.

Croton River.

The records cover two dry periods, the first from June, 1879, to the end of 1883, and the second from 1908 to December, 1913.

During the earlier period the yield was measured at the old Croton Dam, and the results, as given in the report of John R. Freeman to Bird S. Coler, comptroller of the city of New York, dated March, 1900, were used. In obtaining these results no account was taken of the swamps upon the drainage area, which at this time had an area of about 8 sq. miles.

Drainage area, including water surfaces	338.8 sq. miles
Area of water surfaces of reservoirs, ponds, and streams	8.6 sq. miles
Area of land surface	330.2 sq. miles

Full corrections were made for the water drained from or added to storage, although the information relating to some of the smaller ponds and reservoirs was somewhat limited. No allowance was made for the storage in the ground surrounding the reservoirs.

During the interval between 1883 and 1908, the conditions were changed by the building of the new Croton Dam a few miles

downstream from the old dam, thus increasing the storage and drainage area, and by the building of other storage reservoirs upon the tributaries of the river.

The yield is now measured at the new Croton Dam, and information for the period 1908–1913 has been furnished by the Engineering Bureau of the Department of Water Supply, Gas, and Electricity. The drainage area during this later period contained about 7.5 sq. miles of swamps. The area of water surfaces was changed by the completion of the Croton Falls Reservoir on January 1, 1911, but as the reservoirs did not fill in the spring of 1911, no account was taken of the increase of water surfaces due to the construction of this reservoir until the year 1912.

The statistics with regard to land and water surfaces are as follows:

1908–1911, inclusive.

Drainage area, including water surfaces	360.4 sq. miles
Area of water surfaces of reservoirs, ponds, and streams and 40 per cent. of the area of swamps	20.5 sq. miles
Area of land surface	339.9 sq. miles

1912 and 1913.

Drainage area, including water surfaces	360.4 sq. miles
Area of water surfaces of reservoirs, ponds, and streams and 40 per cent. of the area of swamps	22.4 sq. miles
Area of land surface	338.0 sq. miles

During the period 1879–1883 there were three precipitation stations to the end of 1881, and four afterward. During the period 1908–1913 the precipitation has been measured at nine places upon the drainage area.

The drainage area is very hilly and the ground generally of an impervious character. Information is not at hand as to the extent to which the area is forested, but it is probably less than half of the whole area.

The elevation above the sea ranges from 200 to 1 290 ft., and averaged about 620 ft. in the earlier period and about 600 ft. in the later period.

NEW YORK WATER WORKS, 1879.

Yield of Croton River. Total drainage area, 338.8 sq. miles. Area of land surface, 330.2 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	....	....	....	....	....	....	....	....	....	....	....	....
Feb.	....	....	....	....	....	....	....	....	....	....	....	....
Mar.	....	....	....	....	....	....	....	....	....	....	....	....
Apr.	....	....	....	....	....	....	....	....	....	....	....	....
May	....	....	....	....	....	....	....	....	....	....	....	....
June	4 720	−40	4 680	0.476	0.736	0.460	0.712	5.27	0.82	15.6	0.80	15.2
July	3 984	−16	3 968	0.389	0.602	0.378	0.585	5.87	0.70	11.9	0.67	11.4
Aug.	6 728	216	6 944	0.657	1.016	0.661	1.023	6.95	1.17	16.8	1.18	17.0
Sept.	6 030	−120	5 910	0.608	0.941	0.581	0.899	3.32	1.05	31.6	1.00	30.1
Oct.	2 508	−369	2 139	0.245	0.379	0.204	0.316	0.69	0.44	63.8	0.36	52.2
Nov.	2 925	105	3 030	0.295	0.457	0.298	0.461	2.95	0.51	17.3	0.51	17.3
Dec.	8 149	438	8 587	0.795	1.230	0.818	1.266	4.44	1.42	32.9	1.46	32.9
Year	35 014	214	35 258	0.496	0.767	0.486	0.752	29.49	6.11	20.7	5.98	20.3
NEW YORK WATER WORKS, 1880												
Jan.	14 046	369	14 415	1.372	2.123	1.371	2.122	3.43	2.45	71.5	2.45	71.4
Feb.	15 947	351	16 298	1.668	2.581	1.658	2.566	3.40	2.78	81.8	2.77	81.5
Mar.	15 946	329	16 275	1.557	2.409	1.550	2.398	3.90	2.78	71.3	2.76	70.8
Apr.	11 220	90	11 310	1.133	1.753	1.112	1.721	3.57	1.95	54.6	1.92	53.8
May	5 409	−511	1 898	0.529	0.819	0.166	0.721	1.04	0.94	90.3	0.83	79.8
June	2 299	−619	1 680	0.232	0.359	0.165	0.255	1.40	0.40	28.6	0.29	20.7
July	1 537	−18	1 519	0.150	0.232	0.145	0.224	5.86	0.27	1.6	0.26	4.4
Aug.	1 037	−200	837	0.101	0.156	0.080	0.124	4.16	0.18	4.3	0.14	3.4
Sept.	1 424	−254	1 170	0.144	0.223	0.115	0.178	2.42	0.25	10.3	0.20	8.3
Oct.	979	−49	930	0.096	0.149	0.089	0.138	2.83	0.17	6.0	0.16	5.7
Nov.	2 810	10	2 820	0.284	0.140	0.278	0.430	2.32	0.49	21.1	0.48	20.7
Dec.	2 071	161	2 232	0.202	0.313	0.212	0.328	2.59	0.36	13.9	0.38	14.7
Year	71 725	−341	74 384	0.619	0.958	0.600	0.928	36.92	13.02	35.3	12.64	34.2
NEW YORK WATER WORKS, 1881.												
Jan.	4 068	582	4 650	0.397	0.614	0.443	0.686	4.85	0.71	14.6	0.79	16.3
Feb.	26 420	628	27 018	2.857	4.421	2.849	4.408	5.25	4.61	87.8	4.60	87.6
Mar.	35 329	724	36 053	3.451	5.340	3.435	5.315	6.54	6.15	94.0	6.12	93.6
Apr.	10 214	−254	9 960	1.039	1.593	0.980	1.516	1.27	1.78	140.1	1.69	133.1
May	7 225	−61	7 161	0.705	1.091	0.682	1.056	4.03	1.26	31.3	1.22	30.4
June	8 980	−130	8 850	0.906	1.402	0.871	1.348	4.67	1.56	33.4	1.50	32.1
July	2 756	−524	2 232	0.269	0.416	0.212	0.328	2.48	0.48	19.4	0.38	15.3
Aug.	920	−455	465	0.090	0.139	0.044	0.068	2.46	0.16	6.5	0.08	3.3
Sept.	800	−500	300	0.081	0.125	0.030	0.046	0.78	0.14	17.9	0.05	6.4
Oct.	2 480	−31	2 149	0.242	0.374	0.233	0.360	2.95	0.43	14.6	0.42	14.2
Nov.	2 525	445	2 970	0.255	0.394	0.292	0.452	5.23	0.44	8.4	0.50	9.6
Dec.	11 081	699	11 780	1.081	1.673	1.122	1.736	6.18	1.93	31.2	2.00	32.4
Year	112 798	1 120	113 918	0.936	1.448	0.915	1.416	46.69	19.65	42.1	19.35	41.4
NEW YORK WATER WORKS, 1882.												
Jan.	14 665	556	15 221	1.432	2.216	1.449	2.242	4.68	2.56	54.7	2.59	55.4
Feb.	24 670	698	25 368	2.674	4.137	2.672	4.134	5.72	4.30	75.2	4.31	75.4
Mar.	27 093	342	27 435	2.648	4.097	2.610	4.038	3.99	4.72	118.2	4.66	116.8
Apr.	7 552	−232	7 320	0.763	1.180	0.720	1.114	1.42	1.32	93.0	1.24	87.4
May	11 934	218	12 152	1.167	1.806	1.157	1.790	5.92	2.08	35.1	2.06	34.8
June	9 178	−418	8 760	0.929	1.437	0.862	1.335	2.74	1.60	58.4	1.49	54.4
July	3 185	−426	2 759	0.311	0.481	0.263	0.407	3.13	0.55	17.6	0.47	15.0
Aug.	939	−350	589	0.092	0.142	0.056	0.087	3.16	0.16	5.1	0.10	3.2
Sept.	18 139	1 571	19 710	1.830	2.831	1.940	3.002	14.63	3.16	21.6	3.35	22.9
Oct.	11 949	−45	11 904	1.168	1.807	1.132	1.752	2.86	2.08	72.8	2.02	70.6
Nov.	5 045	−95	4 950	0.509	0.788	0.487	0.754	1.61	0.88	54.6	0.84	52.2
Dec.	6 642	147	6 789	0.648	1.003	0.646	1.000	2.49	1.16	46.6	1.15	46.2
Year	140 991	1 966	142 957	1.169	1.809	1.158	1.792	52.35	24.57	46.9	24.28	46.4

NEW YORK WATER WORKS, 1883.

Month	Yield of Drainage Area in Million Gallons: Land Surface	Water Surface	Total Area	Yield per Sq. Mile of Land Surface: Mil. Gal. per Day	Cu. Ft per Sec.	Yield per Sq. Mile of Total Area: Mil. Gal. per Day	Cu. Ft. per Sec	Precipitation on Drainage Area, Inches	Precipitation Collected: Land Surface: Inches	Per Cent.	Total Area: Inches	Per Cent.
Jan.	5 556	365	5 921	0.543	0.840	0.564	0.873	3.40	0.97	28.5	1.01	29.7
Feb.	17 609	647	18 256	1.908	2.952	1.924	2.977	5.38	3.07	57.1	3.10	57.6
Mar.	15 157	12	15 469	1.510	2.336	1 470	2.274	1.78	2.69	151.1	2.63	147.7
Apr.	14 303	67	14 370	1.445	2.236	1 112	2.185	3 42	2.19	72.8	2 41	71.4
May	7 290	−284	7 006	0.712	1.102	0.667	1.032	2.56	1.27	49.6	1.19	46.5
June	3 602	−152	3 450	0.363	0.562	0 340	0.526	4 52	0.63	13.9	0 59	13.1
July	2 209	−163	2 046	0.216	0.334	0 195	0.302	4 89	0.38	7.8	0.35	7.2
Aug.	1 288	−420	868	0.126	0.195	0.083	0.128	2.69	0.22	8.2	0.15	5.6
Sept.	526	−226	300	0.053	0.082	0.030	0.046	2.61	0.09	3.4	0.05	1.9
Oct.	2 423	460	2 883	0.237	0.367	0.271	0.424	6.24	0.42	6.7	0 49	7.9
Nov.	4 453	−103	4 350	0.450	0.696	0 428	0.662	1.56	0.78	50.0	0.74	47.4
Dec.	3 245	320	3 565	0.317	0.491	0.340	0.526	3.65	0.57	15 6	0.60	16.4
Year	77 961	523	78 484	0.647	1.001	0.635	0.982	42.70	13.58	31.8	13.31	31.2

NEW YORK WATER WORKS, 1908.

Total drainage area, 360.4 sq. miles. Area of land surace, 339.9 sq. miles.

Month	Land Surface	Water Surface	Total Area	Mil. Gal. per Day	Cu. Ft per Sec.	Mil. Gal. per Day	Cu. Ft. per Sec	Precipitation, Inches	Land Inches	Per Cent.	Total Inches	Per Cent.
Jan.	22 099	1 133	23 232	2.098	3.245	2.077	3.211	4.14	3.75	90.6	3 71	89.6
Feb.	23 896	1 743	25 639	2.426	3.751	2.453	3.794	5.94	4.05	68.3	4 09	68.9
Mar.	27 008	737	27 745	2.565	3.968	2.483	3.811	3.77	4.57	121.2	4 43	117.5
Apr.	13 091	100	13 191	1.284	1.986	1.220	1 888	3 25	2 21	68.1	2.11	64.9
May	16 119	723	16 842	1.530	2.366	1.507	2.331	6.49	2.73	42.1	2.69	41.4
June	8 736	−1 215	7 521	0.857	1.326	0.695	1.075	2.11	1.48	70.2	1.20	56.8
July	2 626	−1 206	1 420	0.219	0.385	0.127	0.196	2.51	0.45	17.9	0 23	9.2
Aug.	2 959	398	3 357	0.281	0.435	0.301	0.466	6 67	0.50	7.5	0.53	7.9
Sept.	1 523	−1 001	522	0.149	0.230	0.048	0.071	1.07	0.26	24.3	0 08	7.5
Oct.	1 250	−389	861	0.119	0.184	0.077	0.119	1.91	0.21	11.0	0.14	7.3
Nov.	1 436	−365	1 071	0.141	0.218	0.099	0.153	1.01	0.24	23.8	0.17	16.8
Dec.	2 766	520	3 286	0.263	0.407	0.294	0.455	3.38	0.47	13.9	0.52	15.4
Year	123 599	1 178	124 687	0.994	1.538	0.946	1 453	42.25	20.92	49.5	19 90	47.1

NEW YORK WATER WORKS, 1909.

Month	Land Surface	Water Surface	Total Area	Mil. Gal. per Day	Cu. Ft per Sec.	Mil. Gal. per Day	Cu. Ft. per Sec	Precipitation, Inches	Land Inches	Per Cent.	Total Inches	Per Cent.
Jan.	8 140	958	9 098	0.773	1.195	0.814	1.259	4.19	.38	30.8	1.46	32.5
Feb.	22 022	1 532	23 554	2.314	3.580	2.334	3.611	6.33	3.73	59.0	3.76	59.4
Mar.	22 291	975	23 266	2.116	3.272	2.082	3.221	1.73	3.78	80.0	3.71	78.4
Apr.	27 486	1 545	29 031	2.695	4.170	2.688	4.158	7.44	4 65	62.5	4.64	62.4
May	17 902	−787	17 115	1.702	2.632	1.532	2.370	2.24	3.03	135.2	2.73	121.8
June	4 535	−839	3 696	0.445	0.689	0.342	0.529	3.16	0.77	24.4	0.59	18.7
July	1 752	−1 110	642	0.166	0.257	0.057	0.088	2.77	0.30	10 8	0.10	3.6
Aug.	3 569	275	3 844	0.339	0.524	0.344	0.532	6.32	0.60	9.5	0.61	9.7
Sept.	1 851	39	1 890	0.182	0.282	0.175	0.271	4.24	0.31	7.3	0.30	7.1
Oct.	2 221	−588	1 633	0.211	0.326	0.146	0.226	1.25	0.38	30.4	0.26	20.8
Nov.	2 358	252	2 610	0.231	0.357	0.243	0.376	3.11	0.40	12.9	0.42	13.5
Dec.	7 886	869	8 755	0.749	1.159	0.784	1.213	4.56	1.33	29.2	1.40	30.7
Year	122 013	3 121	125 134	0.984	1.522	0.951	1.471	50.64	20.66	40.8	19.98	39.5

NEW YORK WATER WORKS, 1910.

Month	Land Surface	Water Surface	Total Area	Mil. Gal. per Day	Cu. Ft per Sec.	Mil. Gal. per Day	Cu. Ft. per Sec	Precipitation, Inches	Land Inches	Per Cent.	Total Inches	Per Cent.
Jan.	25 436	1 980	27 416	2.415	3.735	2.454	3.795	7.47	4.31	57.8	4.38	58.6
Feb.	17 474	1 390	18 864	1.835	2.839	1.868	2.890	5.24	2.96	56.6	3.02	57.6
Mar.	30 681	−341	30 340	2.912	4.505	2.721	4.210	0.72	5.20	723.0	4.85	672.4
Apr.	12 435	744	13 179	1.219	1.885	1.219	1.885	5.06	2.11	41.6	2.10	41.3
May	12 430	−228	12 202	1.180	1.825	1.092	1.690	3.82	2.10	55.0	1.95	51.0
June	8 632	−448	8 184	0.847	1.310	0.756	1.169	4.28	1.46	31.1	1.31	30.6
July	2 584	−1 307	1 277	0.245	0.379	0.111	0.176	2.26	0.44	19.5	0 20	8.8
Aug.	2 234	−836	1 398	0.212	0.328	0.125	0.193	3.06	0.38	12.4	0.22	7.2
Sept.	1 423	−667	756	0.140	0.217	0.070	0.108	2.10	0.24	11.4	0 12	5.7
Oct.	432	−634	−202	0.041	0.063	−0.018	−0.028	1.13	0.07	6.2	−0.03	−2.7
Nov.	2 791	764	3 555	0.274	0.424	0.329	0.509	4.81	0.47	9.7	0.57	11.8
Dec.	3 088	313	3 401	0.293	0.453	0.301	0.470	2.62	0.52	19.8	0.51	20.6
Year	119 640	730	120 370	0.964	1.492	0.914	1.414	42.60	20 26	47.6	19.23	45.1

NEW YORK WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons. Land Surface.	Water Surface.	Total Area.	Yield per Sq. Mile of Land Surface. Mil. Gal. per Day.	Cu. Ft. per Sec.	Yield per Sq. Mile of Total Area. Mil. Gal. per Day.	Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Land Surface. Inches.	Per Cent.	Total Area. Inches.	Per Cent.
Jan.	7 810	600	8 410	0.742	1.148	0.753	1 165	3.17	1.32	41.6	1.34	42.3
Feb.	8 051	514	8 565	0.846	1.309	0.849	1.311	2.96	1.36	46.0	1.36	46.0
Mar.	11 302	680	14 982	1.358	2.101	1.341	2.074	4.16	2.42	58.1	2.39	57.4
Apr.	19 659	183	19 842	1.929	2.984	1.835	2.839	3.59	3.33	92.8	3.17	88.3
May	6 822	−532	6 290	0.648	1.002	0.563	0.871	2.71	1.15	42.5	1.00	36.9
June	5 016	−678	4 338	0.492	0.761	0.401	0.620	3.26	0.85	26.1	0.69	21.1
July	1 749	−952	797	0.166	0.257	0.071	0.110	2.64	0.30	11.4	0.13	4.9
Aug.	1 914	792	2 706	0.182	0.281	0.242	0.374	8.44	0.32	3.8	0.43	5.1
Sept.	6 128	−353	5 775	0.602	0.932	0.534	0.826	2.76	1.04	37.7	0.92	33.4
Oct.	18 196	974	19 170	1.727	2.672	1.715	2.652	6.75	3.08	45.6	3.06	45.3
Nov.	17 210	619	17 829	1.689	2.612	1.649	2.550	4.33	2.92	67.5	2.84	65.6
Dec.	15 672	563	16 235	1.188	2.302	1.453	2.248	3.29	2.66	81.0	2.59	78.7
Year	122 529	2 410	124 939	0.988	1.528	0.950	1.470	48.06	20.75	43.2	19.92	41.4
NEW YORK WATER WORKS, 1912. Total drainage area, 360.4 sq. miles. Area of land surface, 338.0 sq. miles.												
Jan.	8 647	343	8 990	0.825	1.276	0.80	1.24	2.10	1.47	70.0	1.44	68.6
Feb.	12 756	468	13 224	1.301	2.013	1.27	1.96	2.57	2.17	84.0	2.11	82.1
Mar.	35 635	2 061	37 696	3.401	5.262	3.37	5.22	7.57	6.07	80.2	6.02	79.5
Apr.	23 472	378	23 850	2.315	3.582	2.20	3.41	3.95	4.00	101.3	3.81	96.5
May	26 489	140	26 629	2.528	3.911	2.38	3.69	4.82	4.51	93.6	4.25	88.2
June	7 497	−1 617	5 880	0.739	1.143	0.54	0.84	1.35	1.28	89.8	0.94	69.6
July	1 831	−1 180	651	0.175	0.271	0.06	0.09	2.85	0.31	10.9	0.10	3.5
Aug.	1 929	−441	1 488	0.184	0.285	0.14	0.21	4.28	0.33	7.7	0.24	5.6
Sept.	1 698	−168	1 530	0.167	0.258	0.14	0.22	3.63	0.29	8.0	0.24	6.6
Oct.	2 931	262	3 193	0.280	0.433	0.28	0.44	3.94	0.50	12.7	0.51	12.9
Nov.	8 583	537	9 120	0.846	1.309	0.85	1.31	3.91	1.46	37.3	1.46	37.3
Dec.	10 037	1 030	11 067	0.958	1.482	0.99	1.53	4.63	1.71	36.9	1.77	38.2
Year	141 505	1 813	143 318	1.114	1.770	1.09	1.68	45.60	24.10	52.8	22.89	50.2
NEW YORK WATER WORKS, 1913.												
Jan.	21 492	1 021	25 513	2.338	3.617	2.28	3.53	3.84	4.17	108.6	4.07	106.0
Feb.	9 191	609	9 800	0.971	1.502	0.98	1.50	2.68	1.56	58.2	1.57	58.6
Mar.	34 030	1 713	35 743	3.248	5.025	3.20	4.95	6.18	5.79	93.7	5.71	92.4
Apr.	34 425	945	35 370	3.395	5.253	3.27	5.06	5.42	5.86	108.2	5.64	104.1
May	15 103	−378	14 725	1.441	2.230	1.32	2.04	3.49	2.57	73.6	2.35	67.4
June	4 856	−1 736	3 120	0.479	0.741	0.28	0.44	1.04	0.82	78.9	0.50	48.1
July	1 180	−1 304	−124	0.113	0.175	−0.01	−0.02	2.49	0.20	8.0	−0.02	−0.8
Aug.	1 586	−408	1 178	0.151	0.234	0.10	0.16	4.36	0.27	6.2	0.19	4.4
Sept.	1 909	71	1 980	0.188	0.291	0.18	0.28	4.33	0.32	7.4	0.32	7.4
Oct.	16 037	2 222	18 259	1.531	2.369	1.64	2.53	9.65	2.73	28.3	2.92	30.3
Nov.	16 284	276	16 560	1.606	2.485	1.53	2.37	3.02	2.77	91.7	2.64	87.4
Dec.	12 070	485	12 555	1.152	1.782	1.12	1.74	2.82	2.05	72.7	2.01	71.3
Year	171 163	3 516	174 679	1.387	2.146	1.33	2.048	49.32	29.11	59.0	27.90	56.6

NEW YORK WATER SUPPLY.

Esopus Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at a weir built a short distance below the site of the Ashokan Dam.

The records cover the years 1908–1913.

Drainage area, which contains practically no water surfaces, 239 sq. miles.

The total area of swamps is about 5 sq. miles. These have been neglected in making the computations.

The drainage area includes a large section of the Catskill Mountains, with the steep slopes largely wooded, mostly with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from 590 to 4 200 ft. and averages about 1 700 ft.

The discharge is measured at a masonry weir of ogee section specially constructed for this purpose. The weir should give accurate results when there is no ice. The winters at this place are very severe and the slush ice which forms in a rapidly flowing stream under such conditions and the anchor ice affect the accu-

NEW YORK WATER WORKS, 1908.

Yield of Esopus Creek. Total drainage area (all land surface), 239 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	12 874	1.73	2.68	3.49	3.101	89
February	15 057	2.17	3.36	6.40	3.625	57
March	22 858	3.08	4.77	2.93	5.501	188
April	18 629	2.60	4.02	2.98	4.486	151
May	31 425	4.24	6.56	9.23	7.560	82
June	4 699	0.65	1.01	2.29	1.138	50
July	2 724	0.37	0.57	6.32	0.657	10
August	1 129	0.15	0.23	2.04	0.271	13
September	702	0.10	0.15	2.46	0.169	7
October	3 534	0.48	0.74	4.21	0.852	20
November	3 700	0.52	0.80	0.57	0.892	156
December	4 058	0.55	0.85	2.58	0.977	38
The Year	121 389	1.43	2.21	45.50	29.229	64

NEW YORK WATER WORKS, 1909.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	16 248	2.19	3.39	4.82	3.922	81
February	27 844	4.16	6.44	6.97	6.703	96
March	16 431	2.22	3.43	4.35	3.955	91
April	24 799	3.46	5.35	5.20	5.970	115
May	16 781	2.27	3.51	4.48	4.040	90
June	7 527	1.05	1.62	4.38	1.812	41
July	1 548	0.21	0.33	2.06	0.374	18
August	2 124	0.28	0.44	4.83	0.511	11
September	1 111	0.16	0.24	4.17	0.267	6
October	1 119	0.15	0.23	1.40	0.271	19
November	818	0.12	0.18	1.98	0.199	10
December	3 167	0.43	0.66	4.63	0.760	18
The Year	119 517	1.39	2.15	49.27	28.784	58

NEW YORK WATER WORKS, 1910.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	21 582	2.91	4.50	7.61	5.201	68
February	10 968	1.64	2.54	4.37	2.639	60
March	34 150	4.60	7.12	0.93	8.222	884
April	37 974	5.30	8.19	10.18	9.141	90
May	9 207	1.24	1.92	2.95	2.217	75
June	7 898	1.10	1.70	4.59	1.902	41
July	1 847	0.25	0.38	2.02	0.443	22
August	1 291	0.17	0.27	3.93	0.307	8
September	1 969	0.27	0.42	5.21	0.475	9
October	972	0.13	0.20	1.02	0.235	23
November	2 828	0.39	0.61	3.70	0.681	18
December	4 210	0.57	0.88	2.30	1.017	44
The Year	134 896	1.55	2.40	48.81	32.480	66

NEW YORK WATER WORKS, 1911.

January	11 598	1.56	2.42	2.60	2.802	108
February	6 315	0.94	1.46	1.94	1.527	78
March	10 985	1.48	2.29	3.90	2.655	68
April	19 389	2.70	4.18	2.37	4.671	197
May	6 709	0.91	1.41	1.06	1.616	152
June	9 776	1.36	2.11	5.94	2.355	40
July	2 611	0.35	0.54	3.19	0.629	20
August	1 763	0.24	0.37	4.83	0.421	9
September	3 080	0.43	0.67	4.25	0.740	17
October	18 205	2.46	3.80	7.50	4.392	59
November	11 195	1.56	2.42	3.50	2.701	77
December	10 559	1.43	2.21	2.91	2.552	88
The Year	112 185	1.29	1.99	43.99	27.061	62

NEW YORK WATER WORKS, 1912.

January	6 548	0.89	1.37	2.38	1.577	66
February	8 615	1.24	1.92	2.96	2.071	70
March	29 939	4.04	6.25	5.96	7.208	121
April	33 687	4.70	7.27	5.76	8.107	141
May	16 403	2.22	3.43	4.36	3.948	91
June	3 651	0.51	0.79	1.72	0.876	51
July	1 546	0.21	0.32	3.25	0.370	11
August	4 640	0.63	0.97	7.47	1.116	15
September	2 999	0.42	0.65	3.44	0.718	21
October	7 052	0.96	1.47	4.84	1.698	35
November	11 172	1.56	2.41	4.08	2.691	66
December	14 128	1.91	2.95	4.70	3.415	73
The Year	140 380	1.61	2.49	50.92	33.795	66

NEW YORK WATER WORKS, 1913.

January	23 130	3.12	4.83	4.26	5.569	130.7
February	5 004	0.75	1.16	2.28	1.202	52.7
March	29 760	4.02	6.21	7.70	7.161	93.0
April	14 888	2.08	3.21	3.81	3.583	94.0
May	9 251	1.25	1.93	3.74	2.229	59.6
June	4 476	0.63	0.97	1.01	1.077	106.6
July	824	0.11	0.17	1.90	0.203	10.7
August	876	0.12	0.18	4.86	0.215	4.4
September	1 843	0.26	0.40	4.02	0.445	11.1
October	14 048	1.89	2.93	6.76	3.383	50.0
November	27 164	3.79	5.86	5.60	6.538	116.8
December	9 985	1.35	2.08	2.93	2.405	82.1
The Year	141 249	1.61	2.49	48.87	34.010	69.6

racy of the measurements in the winter season. More accurate measurements can be obtained in the future when the reservoir is in use, as most of the water will be measured through the aqueduct.

Many well-distributed rain gages are used to measure the precipitation on the Catskill drainage areas. Badger weighing gages are used at Sundown and Venetia, a Friez automatic type bucket gage at Brown's Station, and the remainder are 8-in. United States Weather Bureau standard gages, some of them located at the highest elevations at which observers could be obtained. The snowfall is measured by reducing snow collected in gage to water equivalent and measuring. The average depth of snow is also measured on the ground. There are no gages on the tops of the highest mountains, which are inaccessible during a large part of the year. As a result, although the rainfall recorded is very high, especially at the highest stations, showing to a marked degree that the precipitation increases with the elevation, it is probable that the average rainfall upon the drainage area is higher than that recorded.

NEW YORK WATER SUPPLY.

Rondout Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at Honk Falls to and including April, 1910, and at Lackawack from May, 1910, until the end of the period.

The records cover the years 1908–1911.

Drainage area, which contains practically no water surfaces, to April, 1910, inclusive	102 sq. miles
After April, 1910	100 sq. miles

There are no swamps.

The drainage area includes a section of the Catskill Mountains, with the steep slopes largely wooded with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from about 700 ft. to 4 200 ft. and averages about 1 600 ft.

NEW YORK WATER WORKS, 1908.

Yield of Rondout Creek. Total drainage area (all land surface), 102 sq. miles.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	5 206	1.65	2.55	3.12	2.937	94.1
February	6 037	2.04	3.15	6.24	3.405	54.6
March	10 315	3.27	5.06	3.53	5.836	165.3
April	9 075	2.97	4.59	4.02	5.119	127.3
May	9 197	2.91	4.50	7.64	5.188	67.9
June	1 620	0.53	0.82	1.75	0.914	52.2
July	785	0.25	0.39	5.08	0.443	8.7
August	597	0.19	0.29	2.59	0.337	13.0
September	275	0.09	0.14	2.64	0.155	5.9
October	612	0.19	0.29	3.74	0.345	9.2
November	738	0.24	0.37	0.72	0.416	57.8
December	1 437	0.45	0.70	3.09	0.811	26.2
The Year	45 924	1.23	1.902	44.16	25.906	58.7

NEW YORK WATER WORKS, 1909.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	7 669	2.43	3.76	4.82	4.327	89.8
February	12 309	4.31	6.67	6.61	6.944	105.1
March	6 698	2.12	3.28	3.99	3.778	94.7
April	7 219	2.36	3.65	4.71	4.072	86.5
May	6 943	2.20	3.40	3.36	3.917	116.6
June	2 713	0.86	1.33	4.39	1.530	34.9
July	932	0.29	0.45	2.07	0.526	25.4
August	525	0.17	0.26	4.46	0.296	6.6
September	516	0.17	0.26	3.54	0.291	8.2
October	536	0.17	0.26	1.25	0.302	24.2
November	548	0.18	0.28	1.86	0.309	16.6
December	1 154	0.36	0.56	4.47	0.651	14.6
The Year	47 762	1.28	1.98	45.53	26.943	59.2

NEW YORK WATER WORKS, 1910.

Total drainage area (all land surface), January to April, 102 sq. miles; May to December, 100 sq. miles.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	7 081	2.24	3.47	7.07	3.994	56.5
February	4 666	1.63	2.52	4.53	2.632	58.1
March	14 528	4.59	7.10	1.03	8.195	795.6
April	12 078	3.94	6.09	8.30	6.813	82.1
May	4 929	1.59	2.46	3.60	2.836	78.8
June	2 751	0.92	1.42	4.22	1.583	37.5
July	778	0.25	0.39	2.34	0.448	19.1
August	755	0.24	0.37	4.08	0.434	10.6
September	1 350	0.45	0.70	5.25	0.777	14.8
October	691	0.22	0.34	1.18	0.398	33.7
November	1 758	0.59	0.91	3.36	1.012	30.1
December	3 083	0.99	1.53	2.25	1.774	78.8
The Year	54 448	1.47	2.27	47.21	30.896	65.4

NEW YORK WATER WORKS, 1911.

Total drainage area (all land surface), 100 sq. miles.

Month.	Yield of Drainage Area. Mil. Gal.	Yield per Square Mile. Mil. Gal. per Day.	Yield per Square Mile. Cu. Ft. per Sec.	Precipitation on Drainage Area. Inches.	Precipitation Collected. Inches.	Precipitation Collected. Per Cent.
January	5 019	1.62	2.51	3.44	2.888	83.9
February	3 811	1.36	2.10	1.99	2.193	110.2
March	6 072	1.96	3.03	4.42	3.494	79.0
April	9 390	3.13	4.84	3.11	5.403	173.7
May	2 555	0.82	1.27	1.16	1.470	126.7
June	3 954	1.32	2.04	6.57	2.275	34.6
July	1 017	0.33	0.51	3.27	0.585	17.9
August	792	0.26	0.40	5.14	0.456	8.9
September	1 540	0.51	0.79	4.17	0.886	21.2
October	7 765	2.50	3.87	7.10	4.468	62.9
November	5 356	1.79	2.77	3.43	3.082	89.9
December	5 471	1.77	2.74	3.08	3.148	102.2
The Year	52 742	1.44	2.23	46.88	30.348	64.8

The discharge is based upon the height of the water in the stream, which is recorded continuously by a Friez automatic gage; the discharge curve is based upon measurements made with a small Price current meter. It is stated that the accuracy is within 10 per cent., but in the winter in this extremely cold location the results are probably less accurate than when there is no ice.

For information regarding the precipitation, see the Esopus description.

NEW YORK WATER SUPPLY.

Schoharie Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at Prattsville.

The records cover the years 1908–1911.

Drainage area, which contains practically no water surfaces	236 sq. miles

There are no swamps.

The drainage area includes a large section of the Catskill Mountains, with the steep slopes heavily forested with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from 1 130 to 4 025 ft., and averages about 2 000 ft.

Although the Schoharie Creek drainage area has an average elevation somewhat higher than those of the Esopus and Rondout creeks, it is situated beyond a high range of mountains, and slopes towards the west, so that it does not have as high a rainfall as the Esopus and Rondout drainage areas, which slope towards the south and east.

The discharge is based upon the height of the water in the stream, which is recorded morning and evening by an observer. The discharge curve is based upon measurements made with a small Price current meter. It is stated that the accuracy is within 10 per cent., but in the winter in this extremely cold location the results are probably less accurate than when there is no ice.

For information regarding the precipitation, see the Esopus description.

NEW YORK WATER WORKS, 1908.

Yield of Schoharie Creek. Total drainage area (all land surface), 236 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	8 596	1.18	1.82	2.93	2.096	71.5
February	14 299	2.09	3.23	5.51	3.486	63.3
March	19 878	2.72	4.20	2.31	4.846	209.8
April	13 956	1.97	3.05	2.68	3.402	126.9
May	19 182	2.62	4.05	7.53	4.677	62.1
June	2 818	0.40	0.62	2.22	0.687	30.9
July	1 515	0.21	0.32	4.36	0.369	8.5
August	667	0.09	0.14	2.32	0.163	7.0
September	337	0.05	0.07	2.82	0.082	2.9
October	2 587	0.35	0.54	4.31	0.631	14.6
November	1 937	0.27	0.42	0.44	0.472	107.3
December	3 895	0.53	0.82	2.01	0.950	47.3
The Year	89 667	1.04	1.61	39.44	21.861	55.4

NEW YORK WATER WORKS, 1909.

January	12 588	1.72	2.66	4.12	3.069	74.5
February	22 077	3.34	5.16	4.82	5.382	111.7
March	15 446	2.11	3.26	3.38	3.766	111.4
April	20 264	2.86	4.42	4.47	4.940	110.5
May	13 495	1.84	2.84	4.24	3.290	77.6
June	5 650	0.80	1.24	4.19	1.377	32.9
July	1 016	0.14	0.22	1.53	0.248	16.2
August	742	0.10	0.15	3.23	0.181	5.6
September	533	0.08	0.12	3.17	0.130	4.1
October	606	0.08	0.12	1.35	0.148	11.0
November	532	0.08	0.12	1.85	0.130	7.0
December	1 819	0.25	0.39	4.14	0.443	10.7
The Year	94 768	1.10	1.70	40.49	23.104	57.1

NEW YORK WATER WORKS, 1910.

January	15 928	2.18	3.37	6.67	3.883	58.2
February	14 509	2.20	3.40	3.42	3.537	103.4
March	26 285	3.59	5.55	0.62	6.408	1 033.5
April	27 037	3.82	5.91	7.76	6.592	84.9
May	7 544	1.03	1.59	3.07	1.839	59.9
June	9 671	1.37	2.12	5.03	2.358	46.9
July	1 599	0.22	0.34	1.54	0.390	25.3
August	988	0.14	0.22	2.23	0.241	10.8
September	1 089	0.15	0.23	4.22	0.266	6.3
October	1 052	0.14	0.22	0.80	0.256	32.0
November	6 032	0.85	1.32	4.91	1.471	29.8
December	6 737	0.92	1.42	1.45	1.642	113.2
The Year	118 471	1.38	2.13	41.75	28.883	69.2

NEW YORK WATER WORKS, 1911.

January	13 014	1.78	2.75	1.85	3.173	171.5
February	3 694	0.56	0.87	1.13	0.900	79.6
March	11 586	1.58	2.44	2.13	2.825	132.6
April	20 608	2.91	4.50	1.43	5.024	351.3
May	5 724	0.78	1.21	1.43	1.396	97.6
June	9 317	1.32	2.04	6.09	2.271	37.3
July	824	0.11	0.17	2.06	0.201	9.8
August	681	0.09	0.14	4.16	0.166	4.0
September	2 749	0.39	0.60	3.21	0.670	20.9
October	12 305	1.68	2.60	4.68	3.000	64.1
November	7 070	0.99	1.53	1.99	1.724	86.6
December	12 110	1.66	2.57	1.79	2.952	164.9
The Year	99 682	1.16	1.79	31.95	24.302	76.1

Appendix No. 2.

EXPLANATION OF METHODS EMPLOYED IN COMPUTING CAPACITY TABLES Nos. 11 TO 23.

The methods employed can be illustrated best by taking a specific case.

Let it be assumed that Capacity Table 15, page 439, relating to the Wachusett Reservoir, is to be computed to obtain the storage capacity in million gallons per square mile, with various percentages of water surface required to supply the different daily quantities of water given in the first column of the table.

The starting point for computing the second column in the table, which is headed 0 per cent., is a table giving the average yield in gallons per day per square mile of land surface of the drainage area for one, two, or more consecutive months, up to the full number of months contained in the record. Table 3, page 411, is a part of such a table. A reference to it shows that in the driest month the yield was 158 000 gal. daily per sq. mile, so that in a computation dealing only with whole months no storage would be required for a constant draft of this quantity, or less. Hence, there is a 0 in the second column opposite the figures 50 000, 100 000, and 150 000.

When the draft is 200 000 gal. daily, it may be seen by the inspection of Table 3 that the amount of storage required should be based upon the yield for the driest month. The computation is as follows:

	Gallons.
Daily draft	200 000
Daily yield	158 000
Daily deficit	42 000
Deficit for the month	42 000×31 = 1.3 mil. gal.

This is the amount of storage which would theoretically be required to supply 200 000 gal. daily from each square mile of drainage area when there are no water surfaces.

In the case of 250 000 gal. daily, it is not clear from inspection

only whether the reservoir would be depleted to the greatest extent by one, two, or three months' draft, and three separate computations may be made, as follows:

$$\begin{array}{l} 250\ 000 \\ 158\ 000 \\ \hline \ \ 92\ 000 \times 31 = 2.9 \text{ mil. gal. storage on basis of driest month.} \end{array}$$

$$\begin{array}{l} 250\ 000 \\ 190\ 000 \\ \hline \ \ 60\ 000 \times 61 = 3.7 \text{ mil. gal. storage on basis of driest two months.} \end{array}$$

$$\begin{array}{l} 250\ 000 \\ 205\ 000 \\ \hline \ \ 45\ 000 \times 92 = 4.1 \text{ mil. gal. storage on basis of driest three months.} \end{array}$$

These computations show that the greatest amount of required storage is determined on the basis of three months.

For 300 000 gal. daily, the period which gives the maximum storage is again three months.

For 350 000 gal. daily, the period is found to be five months, while for from 400 000 to 650 000 gal. daily the period giving the maximum required storage is six months.

Special attention is called to this case, where the critical period — that is, the one requiring the most storage — is the same for many different daily drafts. In such cases the additional amount of storage required for each increase of 50 000 gal. in the daily draft is constant.

Thus, the storage required to supply from 400 000 to 650 000 gal. daily per sq. mile is as follows:

$$\begin{array}{l} 400\ 000 - 274\ 000 = 126\ 000 \times 184 = 23.2 \text{ mil. gal.} \\ 450\ 000 - 274\ 000 = 176\ 000 \times 184 = 32.4 \text{ mil. gal.} \\ 500\ 000 - 274\ 000 = 226\ 000 \times 184 = 41.6 \text{ mil. gal.} \\ 550\ 000 - 274\ 000 = 276\ 000 \times 184 = 50.8 \text{ mil. gal.} \\ 600\ 000 - 274\ 000 = 326\ 000 \times 184 = 60.0 \text{ mil. gal.} \\ 650\ 000 - 274\ 000 = 376\ 000 \times 184 = 69.2 \text{ mil. gal.} \end{array}$$

It will be noted that for each additional 50 000 gal. daily of draft there is required 9.2 mil. gal. of storage.

When the results of the table are plotted, all portions of the diagram depending upon a given critical period are represented by straight lines. Such uniform increments in the table and straight lines upon the diagram do not represent the general law relating to the required amount of storage, which is that with an increasing draft there is still a greater increase in the required amount of storage.

The diagrams, to cover the general law, should not be made up of straight lines, but should be smooth curves. It has not been thought best, however, to try to make the diagrams for each drainage area represent the general law, but rather to make them so that they will show just the amount of storage required, should there be a recurrence of the conditions which actually existed upon the given drainage area.

A reference to Table 3 shows that the minumum yield per square mile of the land surface of the Wachusett drainage area for twelve months was 582 000 gal. daily. Hence, with any smaller draft than 582 000 gal. daily the assumed reservoir would fill each year, and up to that limit the computations of the required amount of storage are based upon the records of a part of a year. When the daily draft from the reservoir exceeds 582 000, however, the critical period upon which the storage is based may be either less or more than twelve months.

The following computations were made to determine the storage required for a draft of 700 000 gal. daily:

700 000
274 000

426 000 × 184 = 78.4 mil. gal. storage on basis of driest six months.

700 000
376 000

324 000 × 245 = 79.4 mil. gal. storage on basis of driest eight months.

700 000
532 000

168 000 × 488 = 82.0 mil. gal. storage on basis of driest sixteen months.

These computations show that with the draft stated the reservoir would be drawn slightly lower in sixteen months than at the end

of six or eight months. Hence, the required storage is the 82.0 million gal., based upon a critical period of sixteen months.

The remainder of this column was computed in the same manner. The critical period in the case of the highest quantity extends from June 1, 1908, to the end of January, 1914, and if the records for another year were available it might be found that a greater amount of storage than that given in the table would be required.

In order to determine the figures in the remaining columns, that is, the required storage when there are 5, 10, and 15 per cent. of water surfaces, the computations are more extended. The critical period which served as a basis for the figures in the second column often is the same that would serve as a basis for the figures in the other columns, but this rule has many exceptions, as a large evaporation from water surfaces may offset a difference in the rate of run-off from the land surfaces.

The first step in ascertaining the required storage for the three columns above mentioned is to ascertain the net yield of the water surfaces for such single months and periods of consecutive months as seem likely to furnish a minimum yield from land and water surfaces combined.

The yield of a water surface is the difference between the evaporation from and rainfall upon it. The difference gives the net yield per month or months in inches, and this can be converted into the yield in gallons per day per square mile of water surface. The following are examples:

The minimum yield from the land surface of the Wachusett drainage area occurred in October, 1910. The evaporation for October, as given on page 409, is 3.16 in., and the rainfall in October, 1910, was 1.40 in. The difference between the evaporation and rainfall, or the net loss for the month, is 1.76 in., which equals 986 000 gal. per day per sq. mile of water surface.

The yield from the land surface in July, 1913, was low, although greater than in October, 1910. The evaporation for July is 5.98 in. and the rainfall in July, 1913, was 2.37 in. The difference between the evaporation and rainfall is 3.61 in., equal to a net loss of 2 025 000 gal. per day per sq. mile of water surface.

Although the yield of the land surface was 158 000 gal. per day in October, 1910, and 205 000 gal. per day in July, 1913, the loss

by evaporation was enough greater in the latter month to make the yield of land and water surfaces combined smaller. The computations giving this result are as follows:

October, 1910.

95 per cent. of 158 000 gal. daily — the yield of a square mile of land surface — equals.	150 100 gal. daily.	
5 per cent. of —986 000 gal. daily — the yield of a square mile of water surface — equals.	—49 300 gal. daily.	
Net yield of land and water surface combined equals.		100 800 gal. daily.

July, 1913.

95 per cent. of 205 000 gal. daily — the yield of a square mile of land surface — equals.	194 800 gal. daily.	
5 per cent. of —2 025 000 gal. daily — the yield of a square mile of water surface — equals.	—101 300 gal. daily.	
Net yield of land and water surface combined equals.		93 500 gal. daily.

The corresponding yields per square mile of combined land and water surfaces, when the water surfaces amount to 10 and 15 per cent. of the whole area, are as follows:

	Gallons Daily.	
Month.	10 Per Cent. Water Surface.	15 Per Cent. Water Surface.
October, 1910.	40 600	—13 600
July, 1913.	—18 000	—129 500

For periods covering more than one month the same general method is employed, the yield of water surfaces being determined as the difference between the aggregate evaporation and the aggregate rainfall for the whole number of months.

In some cases a period which would give the minimum combined yield of land and water surfaces for one percentage of water surfaces would not give the minimum yield for other percentages. For instance, in the case of the three months' period, the minimum

yield with 5 per cent. of water surfaces occurred from July to September, 1913, while with 10 and 15 per cent. of water surfaces the minimum yield occurred from July to September, 1912.

Having obtained the minimum yield of the combined land and water surfaces for periods of all lengths, the required storage capacity for the last three columns of the table was computed in the same manner as that for the second column of the table, as already described.

DISCUSSION.

Mr. Allen Hazen.* Collecting the records of run-off of streams in very dry periods and putting them in convenient and serviceable form is a useful and necessary work. As I had the honor of appointing this committee, I think I may claim some of the credit for the excellent work that has been done by it.

When Mr. Stearns, chairman of the committee, wrote his report on Water Supplies in Massachusetts, which was published in the annual report of the State Board of Health for 1890, and showed the principles of computing the storage required to maintain desired flows, I think it was generally conceded that the subject was well cleared up for Massachusetts at least, and that the amount of water that could be obtained from a given area could be determined, as well as the size of the reservoir needed to make it available; but as years have gone by it has become apparent that other factors would have to be taken into account. The experience of the past few years, so well set forth in this report, serves to emphasize the divergence from the early standards.

There are a few matters in regard to the report that I wish to mention. In the first place, all the figures in it are computed from the average monthly flows. There is often a substantial difference between the storage computed from the average monthly figures and that which is actually required, depending upon the daily flows. One who has not made a comparison will be surprised at the difference. The difference is not constant. Sometimes it amounts to hardly anything; sometimes to a large figure. Whether it is large or small depends mainly upon whether the

* Civil Engineer, New York City.

storm that breaks the drought occurs in the first or last part of the calendar month in which it happens. This is a matter of pure chance. The tables representing required storage in the report of the committee represent altogether thirteen records of dry periods of different streams, running from a few months to several years. It would be interesting and I think profitable to go through the data again on a daily basis, so that the results entered in the table would rest upon actual daily results and not upon monthly averages. In the case of the smaller rates of draft it would be found that this procedure would sometimes double the amount of storage indicated. In the case of the higher rates of draft the difference would be less relatively, but still important. The committee mentions the fact that monthly averages were used, and that results from daily flows would be greater, but does this in a general way and without bringing it into the tables; and so the tables at present show less storage than would actually be required.

In addition to the storage provided in a reservoir, it frequently happens that the interstices of the soil hold water and give it up slowly and so provide additional storage. This may be called "ground-water" storage. The amount of ground-water storage varies greatly on different catchment areas. It is difficult to study adequately the amount of storage that must be provided in a reservoir without also taking into account the natural or ground-water storage. For the natural storage as far as it goes is just as useful as reservoir storage and reduces the required capacity of the reservoirs. For instance, in the Wachusett area, in some studies recently made, the conclusion was reached that the ground-water storage is sufficient to maintain the supply with a given draft for sixty days longer than the storage in the reservoir would suffice to maintain it if there were no ground-water storage. In the case of some other New England streams, there is practically no ground-water storage. It will be difficult to fully understand storage requirements and to adequately compare one stream with another without in some way taking this ground-water storage into account.

Mr. Stearns has stated the probability that the records accumulated by the committee do not show the driest years that are to be expected upon the several streams, but that still drier

times may be expected. I would put it more strongly, and say that drier times are sure to come. In the case of two streams having the longest records, the committee places side by side the storage requirements for the driest and for the second driest periods: and it is interesting to note that in general terms, and without going into refinements, the driest period on each called for a storage of something like fifty per cent. more than that required to maintain the same draft through the second driest one. In other words, the second driest spell recorded in each case called for only two thirds as much storage as was required to maintain the same output in the driest one. In my judgment, it is only a question of time when droughts will occur so much more severe than those reflected by this record that the amount of storage entered in these tables will be exceeded by another fifty-per cent. Even that is not the limit. It is only a question of how long it will be until still drier periods occur.

The practical question comes as to the use of these tables that the committee has prepared. For the last twenty years much use had been made of records reflecting dry periods of about thirty years ago. Now it appears that, judged by the records of several of the streams, there has been a still drier period. The logical result of consideration of the figures now presented seems to be to mark off from ten to twenty per cent. of the supposed capacities of the water supplies which are re-rated by these records. In other words, a supply supposed for the last twenty years to be capable of furnishing 10 million gallons per day is now going to be marked down to nine or even to eight million gallons per day. We have a new basis, to be used presumably for a certain term of years, until there is a still drier time; and then, following the matter to its logical conclusion, we may expect to have a new and still lower basis of rating than the present one.

The speaker suggests that it is possible, by considering the records of all the years, to form an idea of the nature of the series which they form and of the probabilities of the recurrence of years of given degrees of dryness. The amounts of water that are required in each year to maintain a certain assumed rate of draft from any supply can be easily calculated from the flow records, and these form a never-ending series of quantities. The values

go up and down from year to year, and never repeat themselves. These variations at first sight appear to be purely accidental and outside the range of mathematical calculation; but on study it is found that they can be understood, and that they do have a law and follow it, and that law is in a general way the law of probabilities which is explained in the various text-books on statistics. It is possible, taking the matter up in this way, to use all of the information that is available about the flow of a stream to throw light upon the character of the indefinitely long series of which its record forms one part, and to consider this in connection with similar records of other streams more or less similar to it, to form an idea of the probable frequency of the recurrence of the periods of given degrees of dryness.

The method of rating streams and storage which has been followed by our committee is a method that has been practically in universal use up to the present time. It is based upon the tacit but erroneous assumption that the dry periods of the past will be repeated from time to time in the future.

I have compared the tables prepared by the committee with studies recently presented to the American Society of Civil Engineers for some of the streams for which full data were available; and in a general way, judged by probability methods, the driest years recorded by the committee correspond to what I have otherwise called the ninety-five per cent. dry year. That is to say, in an indefinitely long series of years, about ninety-five years in one hundred may be expected to yield the stated quantities with smaller drafts upon the storage than are shown upon the tables, while the other five years in a hundred will require more storage. In other words, the supply will fall short about one year in twenty.

The subject is an extremely interesting one, and one that furnishes an opportunity for most painstaking study; and I feel that it is one that we shall know more about in a few years than we do now. At the present time this contribution to the really fundamental underlying data is the most important that has been made in this country or any where, and I think the committee is to be thanked most heartily for its work.

Mr. J. M. Diven.* The figures of average rainfall given by the committee for twenty- to forty-year periods agree with the speaker's experience. These records show an average considerably above those made for a term of years running back, say, for ten years. This leads one to wonder if the older records were correct, if they did not err due to the lack of proper measuring devices. If the records are correct and the amount of annual rainfall is gradually growing less, does it not mean trouble in the future? Evidently calculations based on long averages will not be reliable if the records of earlier years of the period are not correct, or if the rainfall was considerably above what we can expect now.

Mr. Theodore H. McKenzie.† Mr. Chairman, I was very much pleased to notice the accuracy and honesty of Mr. Stearns's statements and diagrams with reference to the run-off of different watersheds, and particularly with reference to the matter of the run-off of the Esopus watershed. I have been engaged on a great many cases on that watershed in the employ of claimants.

Most of the engineers engaged for the city have been Massachusetts men, and it has been very difficult to convince them that there was any more run-off there than in the Sudbury and some of the other Massachusetts watersheds, where the ground is sand and gravel, and where the woods have been cut off and the evaporation is large. On the Esopus shed the slopes are precipitous and rocky, with the rock near the surface, and the country well wooded, and also on both sides of the stream the mountains are so high that the sun doesn't get access to the water in the early morning or late afternoon, and the evaporation is necessarily much smaller than on many of the Massachusetts watersheds.

Mr. H. K. Barrows.‡ Our knowledge concerning one of the factors considered in the report of the committee, viz., that of evaporation, is very much less complete than could be wished. The committee have used for data of evaporation from water surfaces the records obtained by Mr. Desmond FitzGerald, which were based upon experiments made at Chestnut Hill Reservoir, near Boston, covering the period 1875–1890.

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†Consulting Engineer, Hartford, Conn.

‡Consulting Engineer, Boston, Mass.

Mr. FitzGerald's experiments were carefully made, the results are accurate and can be used in estimating evaporation where conditions are similar to those at Chestnut Hill, where the records were obtained. We know, however, from measurements of evaporation that have been made in other parts of the country and in other parts of New England, that variation in evaporation from water surfaces in different localities may be very considerable from the figures obtained by Mr. FitzGerald.

In the footnote on page 409, the committee refer to certain measurements of evaporation that were made by the United States Geological Survey between 1905 and 1908, which are published in detail in Water Supply Paper No. 279 of the United States Geological Survey. The average annual evaporation at these Maine stations is a little less than 26 in., as compared with about 39 in. at Chestnut Hill, as found by Mr. FitzGerald. Evaporation experiments at Rochester, N. Y., which began in 1891 and are still in progress, show a mean annual evaporation of about 33 in.

The evaporation for any given month at a given locality does not vary very greatly from year to year, and consequently a few years' observations of evaporation will serve very well in defining the average evaporation to be expected during a given month or during the year.

The measurement of evaporation directly, as described in Water Supply Paper No. 279, is not a matter of great difficulty, and the speaker would like to suggest that such measurements might well be undertaken by water-works departments where large reservoirs are an important part of the water-supply system. The apparatus required is not complicated, and measurements can be made by persons in connection with other regular duties at the reservoir.

Where the percentage of water area in a catchment basin is small, the relative effect of evaporation becomes of less importance, and under such conditions existing data similar to those obtained by Mr. FitzGerald and others will suffice. On the other hand, there are many reservoirs whose area of water surface is a large percentage of the total drainage area. Under these conditions it is important to be able to allow for evaporation more accurately than can be done by the use of general data. Under such condi-

tions it would be well worth while to make measurements of evaporation for a few years, thus obtaining data applicable to the local situation.

MR. ROBERT E. HORTON* *(by letter)*. The report of this committee deals with the available supply of the raw material,—water. Its work is of great value and its report is elaborate. In reading it, it has been found with disappointment that data was collected regarding so few drainage basins. The writer had sincerely hoped that the work of the committee would include the collection of a mass of data giving the natural minimum yield, if only for a few days in each case, of a large number of small watersheds, such as are commonly used as sources of gravity water supply in New England. As the writer will point out, methods of estimating the minimum or safe reliable yield of such streams, based on considerations of rainfall only, cannot be relied upon in such cases. In the writer's opinion, the method of estimating minimum yield from rainfall, outlined by the committee, should be used with extreme caution where the drainage area involved is less than ten square miles, at least. Furthermore, it seems to the writer that the calculation of the minimum flow of streams from the simultaneous rainfall is to a certain extent attacking the problem from the wrong angle. The minimum flow of streams occurs during periods when there is little or no effective rainfall. The problem may be stated in this way: What will the yield be after a period of a certain length of time in months or days with no effective rainfall? Rainfall enters only as a time element in the problem as fixing the duration of the period during which the supply of the stream must come from other sources than direct rainfall. That is, it must come from previously stored precipitation in some form:

1. Surface storage in lakes and marshes, or accumulated snow and ice in winter.
2. Stream channel storage, an item commonly overlooked.
3. Ground-water storage.

Stream channel storage often represents a combination of surface and ground-water storage. Even where a stream is above the general ground-water level, water alternately flows out of the

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stream into the adjacent soil and from the soil into the stream as the stream rises and falls. In the case of Mohawk River, the writer estimates the volume of channel storage in the prism of the main stream and its tributaries, represented by a fall of the stream from bank-full to low-water stage, to be at least two billion cubic feet. This channel storage runs off very rapidly at the start, but more and more slowly as time goes on and as it is more and more augmented by ground-water return from the adjacent banks. It is the writer's observation that channel and adjacent bank storage, excluding ground-water supply in the ordinary sense, is often the controlling element which determines the yield of many small streams during periods of no effective rainfall.

For streams having extensive sand deposits on their drainage basins, ground-water is the controlling element as regards yield during periods of deficient rainfall. For such streams the writer has known the yield to exceed the rainfall during dry summer months. Again, the writer has found for such streams that a knowledge of ground-water level, say on July 1, is a good index of what the yield of the stream will be if there is no effective rainfall during subsequent weeks. The writer regrets that the committee did not attempt to determine the ground-water conditions during the drought in question for the different watersheds studied. These data are very easily obtained where there are unused open or dug shallow wells. Weekly measurements to water surface in each of two or three such wells in a small drainage basin will usually give satisfactory data.

There is a law which governs the relation between duration of drought and flow for natural and unregulated streams. Theoretical and experimental researches by the writer indicate that this law can be determined approximately for many streams from gagings taken during a period of no rainfall for a comparatively short length of time. For the simple case of a stream supplied exclusively from ground water to which there is no accretion during the period of drought, the law of yield of the stream is apparently identical with the "law of natural exhaustion," which runs through a wide range of physical relations between time and quantity, in much the same way as the law of inverse squares is a common relation between distance and quantity.

In its simplest form, —

$$q = q_0 e^{-ct}$$

where q_0 and q are the yield or flow of the stream at the beginning and end of the time t, respectively; c is a constant; e is the base of the Napierian logarithms. This formula requires modification in case of streams deriving their supply during periods of no rainfall from two or more sources, as, for example, from ground water and surface lakes combined. It also requires correction where the ground-water table receives accretions from capillary water in the surface layers of the soil, as is commonly true for quite a long period after the last rain. It is presented here to illustrate a method believed to be new, and a law hitherto apparently overlooked, by which the yield of streams in the absence of rainfall can be estimated more rationally than by attempting to estimate from rainfall, — the one thing which is not there.

The committee discards the Catskill streams, in part, after some discussion of possible causes for the apparently higher run-off than that for New England streams. The writer feels obliged to say that in his opinion the committee has missed an important part of the true explanation. It may be true, as the committee suggests, that the measured yield of Schoharie Creek is somewhat too large during winter periods owing to ice obstruction, but the writer does not believe this is the cause of any serious error in the Esopus Creek records. Since the year 1906 the flow of Esopus Creek has been determined from a well-constructed concrete weir, using coefficients derived from experiments on a similar full-sized model section. The stage of the stream is taken by a recording gage. The writer has made inquiry and is informed that the weir has been kept clear of ice obstruction, with few exceptions for short periods, chiefly during the month of February, and for these periods a reduction, probably adequate, has been made in calculating the discharge. The records taken at this weir agree substantially with parallel records at current meter stations where very numerous measurements were made through the ice to determine the winter flow.

The writer believes that the deficiency in catch of the ordinary rain gage during snowstorms, especially on mountains and in

strong winds, is a very common cause of the discrepancy between observed precipitation and run-off during winter months. The writer has measured snow on the ground in woods in March or early April equal to the entire recorded precipitation for the winter.

There is another factor commonly overlooked heretofore in studying differences in the yield of drainage basins, and that is the run-off of the basin in relation to prevailing wind direction. Omitting polysyllables and using proverb language, "The windward side of the roof catches the rain." Esopus Creek drains part of the southeast slope of the Catskills. The prevailing rain-producing winds come from the southeast. The drainage basin is very precipitous, — the average slope of the landside above Esopus Weir, as determined from the United States Geological Survey topographic map, is 13 degrees 50 minutes. If rain fell vertically, a sloping area would catch the same amount as a flat area of equal horizontal projection, but rain seldom falls vertically. If the rain is deflected by the wind an average of 10 degrees west from the vertical, a little calculation will show that the drainage basin would catch 3.9 per cent. more rain than a flat area of equal size. This increased catch of sloping drainage basins owing to deflection of rain from the vertical is independent of and should not be confused with the increased rainfall sometimes resulting from the upward deflection of wind currents blowing against mountain slopes.

As a further indication that the failure of the Catskill streams to flow in accordance with the categorical and time-honored custom of the Croton, Sudbury, Cochituate, and other New England streams, the writer cites the case of West Canada Creek which, as measured at four different gaging stations, — three of them current meter stations and the fourth having a good concrete dam used as a weir, — has repeatedly shown winter run-off in excess of the measured winter precipitation.

The writer feels that the footnote at the bottom of Table No. 23, page 447, is certainly incomplete and probably in error.

In its conclusion, No. 9, page 469; also on page 431 and page 458, the committee has made statements, perhaps inadvertently, which seem to lead to the conclusion that precipitation always increases with altitude. This is generally true only when there is

more than a certain minimum difference of elevation and when the prevailing rain-bearing winds blow toward the slope. It is true as regards Esopus Creek, but is not true generally in the Adirondacks, since there the precipitation on the westward slope is greater than at higher elevations toward the eastern slope.

The committee estimates the yield of swamps on the basis of 40 per cent. equivalent water surface if undrained, and 30 per cent. if drained. This rule is no doubt correct for some cases, and may approximate the average case. The words "swamp" and "marsh" — the former applying to areas wet but not usually submerged; the latter to areas usually submerged but containing trees or other aquatic vegetation — cover the whole range from open water to dry land.

It is probable that the evaporation loss from swamps, especially those containing the characteristic protruding humps known as "bogs," is generally greater than from open-water surface. The writer would be inclined to think (unless convinced to the contrary by experimental evidence) that the evaporation loss from timber-covered swamps or from marshes filled with reeds and rushes, such as the great Montezuma Marshes in central New York, would also be greater than from open-water surface. If the writer's hypothesis is true, then the whole area of perpetually wet ground with vegetation should be treated as water surface *with an increased evaporation.*

The points raised by the committee as to the relation between elevation and run-off are interesting and, to some extent, at least, new. The report of the committee implies, if it does not directly state, that owing to lower temperature at higher altitudes, the evaporation is necessarily less than it would be at lower elevations, other things being equal. The statement of the committee, on page 409 of its report, as to relation between elevation and evaporation, is incomplete. Evaporation, approximately at least, is a function of the difference between the maximum vapor pressure corresponding to the water temperature and the actual vapor pressure in the atmosphere. Mean temperature decreases about 1 degree Fahr. for each 300 ft. altitude. The maximum vapor pressure decreases with the temperature, and hence with the altitude, and the absolute vapor pressure in the air also decreases

with the altitude. Since both factors governing evaporation decrease with altitude, their difference may either increase or decrease according to their relative rates. The committee has formulated empirical relations between annual precipitation and run-off which may be more or less useful. The rule used by the committee in preparing Table No. 5, page 416, is equivalent to the assumption that 70 per cent. of all rainfall in excess of 40 in. reaches the stream, and that 65 per cent. of all rainfall between 35 in. and 40 in. reaches the stream. It would be more logical to use a sliding scale of percentage of rainfall for rainfalls between 35 in. and 45 in., which would give the same results for these particular values and intermediate results for intermediate values. On this basis, the rule of the committee for estimating annual run-off may be reduced to the following forms:

$$y = 870\ 000 + 47\ 613 (P - 40) \frac{30 + P}{100}; \tag{1}$$

$$\text{or, } y = 870\ 000 + 476.13 (P^2 - 10P - 1\ 200); \tag{2}$$

$$\text{or, } y = 308\ 644 - 4\ 761.3P + 476.13P^2. \tag{3}$$

y = Average annual yield per day, U. S. gallons per square mile.

P = Precipitation, inches.

R = Run-off depth, inches.

$$R = 18.27 + (P - 40) \frac{30 + P}{100}; \tag{4}$$

$$\text{or, } R = \frac{P^2}{100} - \frac{P}{10} + 6.27. \tag{5}$$

Recalculating Table No. 5 by formula (1), above given, tends to reduce the differences between the observed and computed values, and also tends to equalize the sum of the plus and minus departures, thus indicating a somewhat more consistent result. The sum of the plus departures is much greater than that of the minus departures, indicating that the formula is conservative and gives less than the probable average yield. In order to equalize the plus and minus departures so as to obtain the most probable value of the yield, the constant should be taken as 916 000 gal. instead of 870 000 gal., as given by the committee.

The practice was formerly common of applying the Croton, Sudbury, or Cochituate run-off records as "standards" in esti-

mating the yield of all sorts, sizes, and conditions of drainage basins in New England and elsewhere. The methods, charts, and tables furnished by the committee are in effect a modification of this "standard" run-off method, but afford some material improvement in that the number of stream-flow records offered as a basis of selection is relatively large. It does not appear, however, that the problem of greatest importance, namely, the derivation of rational methods of estimating the natural minimum yield of small drainage basins during periods of drought of less than one year has been covered by the report of the committee, and it would seem to the writer proper to extend the work of the committee along these lines.

Yield of Watersheds.

Mr. X. H. Goodnough.* The study of the principles of estimating the storage required to produce a desired yield from a given watershed is a comparatively new one, the first paper on the subject in this country having been presented by Mr. Stearns in the annual report of the State Board of Health in 1890. Up to that time, and for several years thereafter, the observations on the Sudbury River and the Croton watersheds formed the basis of the computation of the yield of most watersheds in New England and its immediate neighborhood. Since then the careful measurement of the flow of streams has been undertaken at other places, but the number of available observations is still a limited one.

The instructions to your committee were to investigate the yields of New England watersheds, and such other watersheds as the committee might deem desirable, during the present dry period, i. e., during the period beginning with 1908. Under these instructions the committee has sought to present actual facts as to the yield of the watersheds in which careful measurements have been made, together with such conclusions as the committee found it practicable to draw therefrom as an aid in solving questions of watershed development arising in the every-day work of the water works engineer and manager.

* Chief Engineer, Massachusetts State Department of Health.

The watersheds vary greatly in character, and the amount of work required to secure satisfactory observations is in most cases considerable. The observations are in nearly all cases kept by calendar months, and this unit was found the most convenient one to use in the study of the results. Where watersheds are developed to the extent commonly found in New England, calculations of yield commonly cover a period of many months, and errors due to the use of monthly records become relatively insignificant. The calculations have included corrections for natural storage and estimated corrections for swamp. They do not include corrections for storage in the ground within the watershed.

Variations due to ground-water storage may be very great, especially in small watersheds. The watershed of Muddy Pond Brook, for example, used as a source of water supply for the town of Stoughton, which has an area of only about 1.1 square miles and contains no natural or artificial storage of any consequence except in the ground, maintains a flow in the stream running out of the watershed which is ample at all times as a water supply for 6 000 people.

During the past summer, in making examinations for a water supply for Salisbury, a stream was found in the northerly part of the town flowing at the rate of 300 000 gal. per day per square mile from a watershed of about half a square mile. The watershed consisted of rolling, sandy country containing no ponds or reservoirs and only about one or two acres of swamp. On the same day the flow of the Ipswich River at a point where its drainage area is 73 square miles amounted to 22 000 gal. per square mile. Probably 20 per cent. of the watershed of the Ipswich River above the point of measurement is swamp land, while the ponds and reservoirs on this watershed are insignificant. These instances are given to show the wide variation which may occur in the natural flow of streams due to ground water storage.

On the Neponset River there is a large amount of underground storage about the great meadows which runs out upon the meadows and keeps large areas of them constantly wet, yet most of this water is evidently lost by evaporation in the drier portion of the year, since the flow of the stream falls at times to very low quan-

tities. If these meadows were provided with drains through which the ground and surface water flowing upon the meadows could find its way quickly to the main river, there is no doubt that the dry-weather flow of the latter would be considerably increased.

Under the conditions found in New England, including the wide variations in the water capacity and yield of the porous strata, it is impracticable to measure ground-water flows in large areas, or even in small areas, without expensive tests. A very fair idea of the probable amount of this ground-water flow can be obtained in some cases, especially in streams draining watersheds containing considerable swamp, by inspection and also by analysis of the water, since in very dry periods when the yield from the swamps ceases, the character of the water of the stream will change greatly if it receives considerable ground water, and the color and organic matter found in the water in ordinary years will become greatly reduced.

Lack of knowledge of ground-water storage unquestionably affects somewhat the yields of the streams examined, and in applying these yields to other streams possible differences due to this cause must be taken into account. Where the period considered is a short one, ground-water storage may be a considerable item in the account, and the writer has had experience, with ponds which, when drawn down, yielded water in considerable excess of the measurable storage in the reservoir itself, and in one case the measurements indicated a storage in the ground amounting to 25 per cent. in excess of the storage of the reservoir. This of course means that the reservoir was surrounded in part at least with very porous soil extending to a considerable depth. Even allowing that the soil was extremely porous, the added reservoir in the ground must have had nearly the same size as the clear capacity of the pond itself when the fact is taken into account that this added reservoir was filled with gravel. Errors of this character largely disappear when the storage development of the watershed is high and a long period is taken into account, and when the area of the watershed is large they are seldom of much effect, but in any case it is usually practicable, after careful inspection and with the aid of experience in the yield of ground waters, to form a fairly accurate judgment as to how much allow-

ance may reasonably be made in a given case for ground-water storage.

In making the observations of the yield of watersheds, the usual method is of course to measure and make allowance for the quantity flowing out of it through its natural outlet, the quantity withdrawn in various ways, and the gain or loss of storage. The result of these computations is often a minus flow when short periods are taken into account, and where the area of water surface is large the minus flow may cover a period of several weeks or even months. This does not of course mean that when the observed yield is a minus quantity the stream ceases to flow. It means simply that the total quantity of water flowing from the land surfaces into the ponds or swamps at such times is lost by evaporation.

Where no water is withdrawn from a watershed and there are no reservoirs upon it, it is a simple matter to gage the stream by means of a weir and thus determine its minimum flow, and this method may be followed even when the flow of water is regulated somewhat by storage.

Some of the complications that may arise in measuring the flow of a stream are illustrated by the case of Lake Quannapowitt at Wakefield, surveyed during one of the recent dry years. The lake has an area of 230 acres, or .36 of a square mile, and its watershed excluding the lake is 3.97 square miles. It contains nearly all the thickly settled portions of Reading and a considerable portion of Wakefield. In the former town 250 000 gal. of water per day are brought into the watershed to supply the inhabitants with water, and, as there are no sewers, this water is discharged into the ground and much of it finds its way to neighboring water courses, judging from the results of their chemical analyses. These water courses, which flow into Lake Quannapowitt, in most cases contain water at all seasons of the year. In Wakefield, also, much water is brought into the watershed from outside, while, on the other hand, water is carried out by sewers, which do not, however, extend to all the portions of the watershed in Wakefield supplied with water.

While there was a flow in all the streams entering the lake at the time of the examination, there was no flow in the stream

running out of the lake, and at the outlet the water of the lake had fallen considerably below the bottom of the outlet channel in the latter part of 1909,—that is, the evaporation from the lake and the amount of water carried out by the sewers more than counterbalanced the yield of the watershed plus the water brought in by the water supplies, and this lake has a minus yield for a period of several months in dry seasons.

In case of ground-water storage, which it is of course impracticable to measure, it may be said that this storage is practically never exhausted and probably enters the streams at a fairly regular rate, though the flow may constantly grow less through a very long period.

The committee has endeavored to present something practical, and, in view of the extensive use made of the earlier studies relating to the flow of streams, and especially the Sudbury and Croton rivers, in the past, it is believed that these observations kept by water works men in New England and its neighborhood will prove of added value in the study of the yield of watersheds. They cannot be applied indiscriminately but, used with judgment, they should make it practicable for the engineer to determine quite closely in most cases the probable yield which can be secured with given storage on a given stream in the larger part of New England and eastern New York. In thus applying the records, full consideration must of course be given to other circumstances, such as the situation of the city or town to be supplied and the ease or difficulty of obtaining an emergency additional supply in case of the exhaustion of the regular source.

It is usually an easy matter to secure an additional supply of good water amounting to 50 000 or 100 000 gal. per day, and it is usually not a difficult matter to obtain a temporary supply of 200 000 or 300 000 gal. per day. With larger supplies the difficulty of securing a suitable auxiliary supply increases; but, since in practically all cases the larger surface water supplies in New England and eastern New York are obtained from storage reservoirs, observations of the decrease in the quantity of water in storage will, studied in connection with these records, give ample warning of the possible danger of shortage and afford an opportunity to provide against it either by an enforced reduction in

the consumption of water or the introduction of an auxiliary supply. There is often a sanitary question involved in the maintenance of ample storage, since long storage is one of the most potent factors in the destruction of disease-producing organisms which may enter a water supply and also in the improvement in the quality of the water in other respects.

It is hoped that one advantage which the Association may derive from the presentation of these studies will be that the increased interest aroused in this subject will lead to the establishment of a greater number of observations of rainfall and stream flow in various parts of New England, thus furnishing additional data which will be of great value, especially when compared with the information here collected.

The following table is similar to Table 30 on page 466, and gives the minimum flow of certain drainage areas in gallons daily per square mile for periods ranging from one week to three months.

Drainage Area. Name.	Square Miles.	Year.	Period. One Week.	Two Weeks.	One* Month.	Two† Months.	Three‡ Months.
			Million Gals. per Day.				
Ipswich River at East Street, Middleton . . .	73.02	1911	.024	.029	.069	.120	.150
		1912	.037	.046	.058	.083	.109
		1913	.011	.014	.031	.042	.059
		1914	.006	.006	.010	.015	.030
Ipswich River at Willowdale	119.9	1911	.058	.060	.094	.164	.196
Charles River at Charles River Village	184.0	1914	.137	.146	.151	.163	.180

*One month=driest period of 30 consecutive days.
†Two months=driest period of 60 consecutive days.
‡Three months=driest period of 90 consecutive days.

In making the measurements given in the above table, no allowance has been made for storage. Storage on the Ipswich River is practically insignificant except for the temporary storage in swamps. The percentage of swamp area on this river is very large, and the swamps are of such a character that they do not drain freely into the river. In the watershed of the Charles

River the amount of storage, while larger than on the Ipswich, is not great. There is a very large area of meadow land in the watershed of this stream, but the extensive meadows above Medfield are for the most part considerably above the level of the river in dry periods. There are extensive deposits of sand and gravel in the valley of this stream above the point of measurement, which no doubt have a considerable influence in maintaining the dry-weather flow.

Table 4 on page 414, entitled "Comparison of Run-Off in Years of High and Low Precipitation," shows that on the Wachusett watershed 77 per cent. of the excess of precipitation in the highest four years recorded over the lowest four years ran off into the stream. Similarly on the Sudbury watershed, comparing the highest six years with the lowest six years, it appears that 82.9 per cent. of the excess in wet years ran off into the streams.

If, instead of considering the entire year, the wettest six-month periods in each year only — that is, from December to May inclusive — are compared, it will be found that a still larger per cent. of the run-off is collected into the streams when the precipitation is large than when it is small. The results of this comparison are shown in the following table, both for the Wachusett and Sudbury watersheds.

Drainage Area.	Period.	Average Precipitation. Inches.	Average Run-off. Inches.	Per Cent of Run-off.
Wachusett (December to May inclusive)	Highest 4 yrs.	28.09	21.929	78.1
	Lowest 4 yrs.	17.51	11.920	68.1
	Difference	10.58	10.009	94.6
Sudbury (December to May inclusive)	Highest 6 yrs.	28.65	21.568	75.3
	Lowest 6 yrs.	17.66	10.843	61.4
	Difference	10.99	10.725	97.6

The foregoing table shows that in the wetter portion of the year the run-off from the difference between the precipitation of the highest and lowest years is, on the Wachusett watershed, 94.6 per

cent., and on the Sudbury watershed, 97.6 per cent. of the rainfall.

The following table gives a similar comparison of the average run-off for the years of highest and lowest rainfall in the months from June to November inclusive, the drier part of the year.

Drainage Area.	Period.	Average Precipitation Inches.	Average Run-off. Inches.	Per Cent. of Run-off.
Wachusett (June to November inclusive)	Highest 4 yrs.	29.44	10.111	34.3
	Lowest 4 yrs.	16.04	2.480	15.4
	Difference ...	13.40	7.631	56.9
Sudbury (June to November inclusive)..	Highest 6 yrs.	30.26	9.047	29.9
	Lowest 6 yrs.	14.83	.708	4.8
	Difference	15.43	8.339	54.0

This latter table shows that 56.9 per cent. of the excess of rainfall in the period from June to November inclusive, is collected in the streams on the Wachusett watershed, and 54 per cent. on that of the Sudbury.

MR. WILLIAM S. JOHNSON.* Mr. Chairman, there is no question that this is a very valuable report and will be of great use to many of us. There are one or two points which I would like to bring up, concerning which I at least would like further information.

Many of our watersheds contain a large proportion of swamp area, and the yield of these areas is an important part of the total yield. Mr. Stearns and Mr. Goodnough know more about this than almost anybody else, and I have no doubt that their conclusions are correct, but I think it would be of interest to many of us to know how they arrive at the percentages which they use, whether they are based on measurements, or are simply a matter of judgment. I have been brought up to believe that the yield of a swamp was very much less than the yield of a corresponding water area during the summer months. Meadow grass, we are

* Consulting Engineer, Boston, Mass.

told, will use up while growing from thirty to forty inches of water, provided it can get it. Those of us who have waded around in swamps on a hot, sunny day know that the water in a meadow exposed to the sun is very much warmer than the water in a pond or a stream even on the surface, and that would favor evaporation. So that I always supposed that if you add the large amount which is used up by the meadow grass in growing, and that which evaporates directly into the air, the evaporation would be very much greater than it would from a water surface. In the winter months, of course, the conditions are quite different and there would be a difference between open meadow and alder swamps. Some of our watersheds, like that which Mr. Goodnough referred to, the Ipswich River, contain enormous areas of meadows, and it is very important to know something about what the yield of such areas is.

The other matter is that of evaporation. Of course everybody uses the classic results of Mr. FitzGerald's experiments. The committee says that the average monthly results may be used without serious error, because the evaporation for a given month in different years does not vary very much. As I remember Mr. FitzGerald's experiments, there was a very considerable difference in the evaporation in different years, and if you are considering the yield of a pond with a water surface as large or nearly as large as the land surface, this difference in the evaporation enters into it very seriously. I remember that the total evaporation for a year varied about thirty per cent., and I have run up against that in several rather important cases, where it was important to know what the yield of the water surface was. I have been somewhat embarrassed in trying to maintain my position based on the average results of these evaporation experiments, because of the considerable variation. To use the average did not seem quite right even to my own mind, and to those on the other side of the case it seemed very far from right.

Mr. Frederic P. Stearns.* Replying to Mr. Diven's remarks, the average rainfall for the last ten years is, as he states, considerably less than for the last twenty and forty years. The result is not due to incorrect records, as the measuring devices in use forty years ago were excellent and the records were kept with

*Consulting Engineer, Boston, Mass.

care. If one had only the records for the last forty years it might be reasonable to infer that the rainfall was diminishing, but there are good records of rainfall extending back to 1820, and still more extending back to 1830, which show that there were probably drier periods in the first half of the last century than in recent years. These older records may not be quite as accurate as recent records, but they are sufficiently trustworthy to prove that there were periods of as low, if not lower, rainfall eighty or ninety years ago than recently.

Mr. Hazen has called attention to several matters which should be considered in the practical use of the tables, and it is well that these features should be emphasized. The committee fully recognized that the tables and diagrams might be improperly used in the manner which he has suggested and in other ways, and has attempted to prevent such use by explaining the conditions and character of the records upon which the tables and diagrams were based, and under the head of "Caution" has explained the various inaccuracies which might result from unintelligent use. Under this head one reference is to the inaccuracy due to basing tables on monthly instead of daily yields, a matter which has been brought up by Mr. Hazen, and the recommendation is made that this be offset by providing storage equal to a month's supply of water in addition to the amount of storage indicated by the use of the tables.

Mr. Hazen has suggested that it might be interesting and profitable to go through the data again on a daily instead of a monthly basis, but this cannot be done with the data collected by the committee, because the records furnished were on a monthly basis. The committee gave this matter consideration at the beginning of the investigation, and concluded that it would be more likely to get practical results if it asked for the records of average monthly instead of daily flow. It seemed that more would be lost than gained by attempting such a refinement.

The ground-water storage is in some cases, as Mr. Hazen suggests, a valuable addition to the visible storage. The records obtained from each stream necessarily represented the flow as affected by the ground-water storage of the drainage area in general, and the ground-water storage around the margins of

reservoirs to the extent that it was drawn upon by the lowering of the water in the reservoirs. Such records are, therefore, directly applicable to the drainage areas from which they are derived, but in deducing the yield of one drainage area from the yield of another, this matter should be taken into consideration. When the drainage area is fully developed, so that the storage is sufficient to equalize the flow of a stream for a series of dry years, this feature is one of minor importance.

The point that has been raised that there may be much drier years than those included in the recent dry period is one with which the speaker agrees, and it seems reasonable to assume that the driest year of the recent period represents what Mr. Hazen has called the "ninety-five per cent. dry year"; so that five years in a hundred will be drier.

Judging from past experience, more than one of these years are likely to come in dry periods, so that at times they may be only two or three years apart, like the dry years 1880 and 1883; and at other times there may be an interval of thirty or forty years between such extremely dry years.

The recent period has been remarkable in including not only an extremely dry year but a long series of *consecutive* dry years, and such a series is not likely to recur nearly as often as the individual dry year. From the information now available, it seems unlikely that such a series will recur more frequently than once in a century.

When a source of supply is highly developed by ample storage, its safe capacity is based upon the yield in a series of consecutive dry years, and for such sources the yield based on the recent dry period will be very conservative. With a smaller development of a source, so that its safe capacity is based upon the yield of a single year, it is much more important to take into account the probability of still drier years.

Mr. Hazen has made the suggestion that, as the safe capacity of sources of water supply based on the recent dry period is from ten to twenty per cent. less than one based on the dry period of about thirty years ago, we may expect in future years to have a new and still lower basis of rating than the present one. Referring to this suggestion, the speaker wishes to emphasize the

point made in the report that the safe capacity of a given water supply is to a large extent a question of practical judgment and not a fixed quantity as set forth by tables and diagrams.

A city which is depending upon the natural flow of a stream, or upon a storage reservoir which may be exhausted during the dry period of a single year, should reckon the safe capacity of its source on a basis of much drier years than have yet been recorded, unless it can obtain an additional emergency supply in a short time. It is not good policy to provide for those things which happen only once in from twenty-five to fifty years when the expenditure of a moderate amount of money can meet the emergency if it comes.

On the other hand, a large city which cannot obtain an emergency supply at short notice should be very conservative when determining the safe capacity of its sources.

To use Mr. Hazen's nomenclature, one city should base the safe capacity of its sources on a 98 or 99 per cent. dry year, while another may have its water supply equally well guarded against failure if it bases the safe capacity on an 85 or 90 per cent. dry year.

A city which has a great reservoir which cannot be exhausted in less than from four to six years is fully warranted in continuing to use water from such a source until the safe capacity of the source, based upon past experience, has been materially exceeded, because if the extremely dry period arrives there is sufficient time to obtain an additional supply, or at least an emergency supply.

The speaker does not agree with Mr. Hazen's view that the method followed by the committee is based upon the "erroneous assumption that the dry periods of the past will be repeated from time to time in the future." There is no evidence of any permanent increase or decrease in the annual amount of rainfall, and it therefore seems far from erroneous to make the assumption stated.

The existing records show that the recent dry period includes the driest year and the driest period in the last sixty-four years, but this is not a long enough time to insure that drier periods will not occur. It is for this reason that it may in some cases be necessary for safety to assume the occurrence of still drier periods, but this is not a suitable basis for the view that the dry periods of the past will not recur.

The speaker does not agree with Mr. McKenzie's reason for the yearly excess of run-off from the Esopus drainage area as compared with that of other drainage areas. The conditions mentioned by him as favorable to a large run-off, if they are controlling, ought to be operative in the dry portions of the year as well as at other times, and yet the records of the minimum flow of different drainage areas for periods ranging from one week to three months, as given in Table 29, show that the Esopus and other Catskill Mountain areas yield rather less water during such portions of the year than ordinary streams.

Mr. Horton, in his criticism of the committee's report, appears to lay special stress upon the desirability of collecting "a mass of data giving the natural minimum yield, if only for a few days in each case, of a large number of small watersheds, such as are commonly used as sources of gravity water supply in New England." The committee furnished such data upon this point as was available at the time of making the report, and has added at the end of the report an additional record based upon the discharge of a stream in the latter part of 1914. The committee did not think, however, that the records for short periods had as much value as those for longer periods, for the reason that it is impossible to predict that extremely dry periods of a few days, or even of a few months, may not be followed by very much drier periods in the future. The committee, therefore, emphasized in its report the view that dependence should not be placed on the recorded minimum flow of small streams for short periods, but that storage should be provided to tide over such periods, even if the flow in the future should be much smaller than anything preciously recorded.

Mr. Johnson refers to the yield of swamp areas as being in some cases an important factor of the total yield of drainage areas, and asks whether the percentages used by the committee are based on measurements or are simply a matter of judgment. They are simply a matter of judgment, because no experimental information was at hand to show how much water evaporates from swamps. It has been the rule in the past, when making computations of the yield of drainage areas, to ignore the difference between the yield of swamps and other land surfaces, and the committee thought it better to take into account the smaller

yield from swamps, even though the correction was necessarily based on judgment. It was better to make a correction which might not be at all precise rather than not to make any.

The assumption was made in the report that undrained swamps might be considered as equivalent to 40 per cent. of water surfaces and 60 per cent. of upland surface, and in the case of drained swamps 30 per cent. was used in place of the 40 per cent. These percentages were intended to represent the average swamp of New England, a large proportion of such swamps containing trees and bushes and becoming reasonably dry in the hot weather of summer.

Mr. Johnson appears to refer to swamps of a different character, in which water is standing and meadow grass is growing. The evaporation from such areas would undoubtedly be much larger than is provided for by the rule of the committee.

The evaporation experiments by Mr. FitzGerald show that during the five months from May to September inclusive, there is on an average 25.6 in. of evaporation from water surfaces. It does not seem probable that as much water as this would be available for evaporation from the surface of most swamps, or that so great an amount of water would be evaporated from wooded swamps which are fairly dry during a part of these months.

The speaker agrees with Mr. Johnson that more information as to the yield of swamps is desirable.

As to the question of evaporation from water surfaces, it is well known that the amount per month differs from one year to another, as stated by Mr. Johnson, and the suggestion of the committee that average monthly results may be used without serious error was based upon the fact that the monthly evaporation in any given year does not as a rule vary widely from the average for a series of years, and the water surfaces to which the evaporation is applied are generally only a small fraction of the whole surface of the drainage area.

As suggested by Mr. Barrows, further light on the subject of evaporation from water surfaces is desirable, and the results obtained in Maine and at Rochester are lower than those obtained by Mr. FitzGerald. A part of this difference can be accounted for by the difference in temperature.

PROCEEDINGS.

HOTEL BRUNSWICK, BOSTON, MASS.,
November 11, 1914.

President Frank A. McInnes in the chair.
The following members and guests were present:

MEMBERS.

L. M. Bancroft, F. A. Barbour, A. E. Blackmer, J. W. Blackmer, R. L. Cochran, C. A. Bogardus, E. C. Brooks, Fred. Brooks, W. H. Butler, J. C. Chase, R. D. Chase, J. E. Conley, J. H. Cook, G. K. Crandall, E. D. Eldredge, A. L. Fales, G. H. Finneran, F. F. Forbes, F. B. Forbes, Patrick Gear, H. T. Gidley, Albert S. Glover, F. E. Hall, A. R. Hathaway, T. G. Hazard, Jr., D. A. Heffernan, A. C. Howes, H. C. Ives, H. R. Johnson, E. W. Kent, Willard Kent, G. A. King, F. A. McInnes, Thomas McKenzie, Hugh McLean, A. E. Martin, W. E. Maybury, John Mayo, William Naylor, F. L. Northrop, T. A. Peirce, H. E. Perry, Dwight Porter, A. L. Sawyer, W. B. Schwabe, J. E. Sheldon, C. W. Sherman, E. C. Sherman, G. H. Snell, G. A. Stacy, G. T. Staples, W. F. Sullivan, W. C. Tannatt, Jr., R. J. Thomas, D. N. Tower, C. H. Tuttle, Ernest Wadsworth, R. S. Weston, G. C. Whipple, J. C. Whitney, F. I. Winslow, G. E. Winslow. — 62.

ASSOCIATES.

Ashton Valve Company, by H. H. Ashton; Builders' Iron Foundry, by A. B. Coulters; Chapman Valve Manufacturing Company, by J. J. Hartigan; *Engineering News*, by I. S. Holbrook; *Engineering Record*, by N. C. Rockwood; Hersey Manufacturing Company, by Albert S. Glover, S. B. Greene; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor and G. A. Miller; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; National Water Main Cleaning Company, by B. B. Hodgman; Neptune Meter Company, by H. H. Kinsey and R. C. Wertz; Pitometer Company, by E. D. Case; MacBee Cement Lined Pipe Company, by J. D. MacBride; Rensselaer Valve Company, by F. S. Bates and C. L. Brown; Ross Valve Manufacturing Company, by William Ross; A. P. Smith Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Thomson Meter Company, by E. M. Shedd; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison. — 27.

GUESTS.

Thomas G. O'Connell, water commissioner, Wakefield, Mass.; Max von Recklinghausen and R. E. Case, New York, N. Y.; J. N. Smith, Wollaston, Mass.; George Smith, Norwood, Mass.; George H. Smith, F. M. Bates, Boston; Prof. L. Mitchell, Syracuse, N. Y.; James S. Davine, chairman water board, Westfield, Mass.; Harrison B. Freeman, president Northern Connecticut Light and Power Company, Thompsonville, Conn.; Stanley Osborne, M.D., W. R. Holway, LeRoy M. Peterson, Harriet Pack, Forest Funk, H. E. Berger, E. H. Magoon, T. R. Kendall, M. W. Cowles, Frances Lord; Aimi Caismion; C. E. Buck, G. S. Fowler, E. S. Tisdale, S. L. Tolman, R. V. Tiffany, Huet Massie, and P. Masucci, Boston, Mass — 28.

The Secretary presented the following applications for membership, properly endorsed and recommended by the Executive Committee:

Bernard F. Rogers, Charlestown, Mass., master plumber, foreman Boston Water Department, Water Service; William T. Lenehan, Dorchester, Mass., foreman City of Boston Water Service; S. Nishioeda, Tokio, Japan, Tokio Municipal Water Works; Estus H. Magoon, Dorchester, Mass., assistant professor of hydraulic and scientific engineering, Massachusetts Institute of Technology; Ernest B. Black, Kansas City, Mo., engaged in water supply and purification particularly; Walter H. McMahon, Chelmsford, Mass., superintendent of the water district; Elmer G. Manahan, Mt. Vernon, N. Y., had charge of filtration division, Department of Water Supply, Gas, and Electricity, New York City, now in charge of designing division of this department; Thomas E. Lally, Boston, Mass., engineering work in Boston Water Department; George A. Stowers, Billerica, Mass., assistant engineer water pipe, superintendent of water department; William F. Clark, Winchendon Mass., superintendent water works; Frederic H. Fay, Boston, Mass., consulting engineer, Fay, Spofford & Thorndike; Edward F. Hughes, Watertown, Mass., water commissioner; Frederick L. Waldmyer, Winchester, Mass., water registrar; Raymond J. Andrus, Montesano, Wash., vice-president and general manager Northwest Electric and Water Works; M. Cashman, Newburyport, Mass., contracting, has done practically all building of filter beds, reservoirs, and laying pipes for the Newburyport Water Works for the past twenty years; Sturgis H. Thorndike, Boston, Mass., consulting engineer; Charles M. Spofford, Boston, Mass., consulting engineer; James Fitzgerald, West Acton, Mass., superintendent of water supply district; A. H. Grindle, Bar Harbor, Me., superintendent Bar Harbor Water

Company; George O. Adams, North Andover, Mass., chemist with State Department of Health; Harold P. Buttenheim, editor of *The American City*, New York City; Power Equipment Company, T. H. Holmes treasurer, Boston, Mass.; H. F. Jenks Co., Inc., Pawtucket, R. I.; William T. Dotten, Winchester, Mass., superintendent water works,— applicant for reinstatement.

On motion the Secretary was directed to cast the ballot of the Association in favor of the applicants, and he having done so they were declared duly elected members of the Association.

THE PRESIDENT. There is one thing I would like to say. The Executive Committee are now considering the question of the meeting place for the annual convention of next year. Their mind is entirely open in the matter, and the Executive Committee as a whole would welcome suggestions. After the meeting is over, in the hotel and corridor, we would be delighted to hear suggestions; or write to any member of the committee just what you think about it.

The first paper of the afternoon was entitled "Sterilization of Water with Ultra-Violet Rays," by Max von Recklinghausen, Ph.D., Strassburg. After reading his paper Dr. Recklinghausen answered questions by Mr. John C. Whitney and Mr. Tannett of Easthampton.

"The Use of Ozone as a Sterilizing Agent for Water Purification" was the subject of a paper by Sheppard T. Powell, chemist Baltimore County Water and Electric Company. Mr. Powell not being present, his paper was read by Mr. F. B. Forbes. The author of the paper being absent, the President did not invite discussion upon it.

The next paper on the program was entitled "Water Rates," by B. M. Wagner, C.E., Rockville Center, N. Y. Mr. Wagner was not present, and as the paper was in print and will be published in the JOURNAL, the President declared it read by title.

The topical discussion was on the general subject of Service-Pipes, — methods used; methods of making connection at main; depth of laying; troubles from freezing; methods of thawing, etc. The discussion was opened by Mr. E. C. Brooks and Mr. F. F. Forbes, and the following-named gentlemen participated in it: George H. Finneran, George A. King, John H. Flynn,

William Naylor, John C. Whitney, Charles W. Sherman, Lewis M. Bancroft, R. D. Chase, D. A. Heffernan, G. A. Caldwell, George A. Stacy, Robert S. Weston, W. F. Sullivan, T. G. Hazard, Jr., Edward D. Eldredge, Patrick Gear, George E. Winslow.

HOTEL BRUNSWICK, BOSTON, MASS.,
December 9, 1914.

President Frank A. McInnes in the chair.
The following members and guests were present:

MEMBERS.

A. F. Ballou, L. M. Bancroft, F. A. Barbour, G. W. Batchelder, A. E. Blackmer, J. W. Blackmer, C. A. Bogardus, Dexter Brackett, E. C. Brooks, G. A. Carpenter, George Cassell, J. C. Chase, R. C. P. Coggeshall, F. L. Cole, J. E. Conley, A. W. Cuddeback, G. W. Cutting, Jr., F. W. Dean, E. R. Dyer, E. D. Eldredge, G. F. Evans, F. F. Forbes, Albert S. Glover, Clarence Goldsmith, J. W. Graham, R. K. Hale, F. E. Hall, E. A. W. Hammatt, C. R. Harris, L. M. Hastings, T. G. Hazard. Jr., D. A. Heffernan, D. J. Higgins, A. W. Jepson, W. S. Johnson, Willard Kent, G. A. King, J. J. Kirkpatrick, F. A. McInnes, Hugh McLean, W. H. McMahon, John Mayo, J. H. Mendell, F. E. Merrill, G. F. Merrill, H. A. Miller, F. L. Northrop, T. A. Pierce, H. E. Perry, D. C. Randall, C. L. Rice, L. C. Robinson, W. J. Sando, C. M. Saville, A. L. Sawyer, J. E. Sheldon, H. H. Sinclair, G. H. Snell, G. T. Staples, W. F. Sullivan, R. J. Thomas, E. J. Titcomb, D. N. Tower, C. H. Tuttle, W. H. Vaughn, R. S. Weston, G. C. Whipple, F. B. Wilkins, F. I. Winslow, I. S. Wood. — 70.

ASSOCIATES.

Builders' Iron Foundry, by A. B. Coulters and A. A. Wood; Chapman Valve Manufacturing Company, by J. F. Mulgrew; Darling Pump & Manufacturing Co. (Ltd.), by J. L. Hough and H. A. Snyder; *Engineering Record*, by I. S. Holbrook; *Engineering News*, by N. C. Rockwood; Hersey Manufacturing Company, by Albert S. Glover, Walter A. Hersey, S. G. Greene; Kennedy Valve Company, by M. J. Brosnan; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by J. H. Caldwell and A. R. Taylor; MacBee Cement Lined Pipe Company, by J. D. MacBride; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; National Tube Company, by H. T. Miller; Neptune Meter Company, by H. H. Kinsey; Pittsburgh Meter Company, by J. W. Turner; Platt Iron Works Company, by F. H. Hayes; Rensselaer Valve Company, by C. L. Brown and F. S. Bates; A. P. Smith

Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Union Water Meter Company, by F. E. Hall and E. K. Otis; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison and E. P. Howard. — 33.

GUESTS.

S. D. Soule, superintendent Gardiner Water District, Gardiner, Me.; Arthur E. Weeks, New Bedford, Mass; George A. Stowers, superintendent water works, Billerica, Mass.; N. B. Tower, R. B. Tower, Cohasset, Mass; Donald Green, assistant engineer, Greenfield, Mass.; Frank Bates, Boston; Smith F. Ferguson, New York, N. Y. — 8.

The Secretary presented the following applications for membership, properly endorsed and recommended by the Executive Committee:

Resident: Oliver E. Williams, Boston, Mass., vice-president of the Tiffin, Ohio, Water Works; M. W. Carroll, Millers Falls, Mass., water commissioner of the Millers Falls Water Supply District; Roland F. Kay, Milford, Mass., meter inspector, Milford Water Works; Walter N. Charles, New Bedford, Mass., New Bedford Sewage Disposal Plant; George F. Ashton, Salem, Mass., city engineer; H. E. Crowell, Haverhill, Mass., superintendent water works; William A. Tripp, Vineyard Haven, Mass., engineer for Tisbury Water Works; Isaac Osgood, Boston, Mass., electrical and fire insurance engineer; Leon Edward Dix, Northfield, Vt., assistant professor of civil engineering, Norwich University; Moses L. Brown, Quincy, Mass., commissioner of public works; Eugene Carpenter, Newton, Mass., constructor of water supply plants; C. W. Whiting, Boston, Mass., consulting engineer; J. Harold Remick, Littleton, Mass., superintendent of water works and municipal light plant; John G. Whitman, Quincy, Mass., superintendent water works.

Non-resident: Henry W. Taylor, Albany, N. Y., assistant engineer, City of Rochester, N. Y., and New York Department of Health, and consulting engineer for various municipalities; R. C. Harris, Department of Water Works, Toronto, Canada; S. F. Ferguson, New York City, member of the firm of Nicholas S. Hile & S. F. Ferguson, consulting engineers; Philip Burgess, Columbus, Ohio; and R. C. Harris, Toronto, Ontario.

The Secretary was directed to cast the ballot of the Association in favor of the applicants, and he having done so they were declared duly elected members of the Association.

The first paper of the afternoon was entitled "A Description of the Water Supply System of Cohasset, Mass.," by D. N. Tower superintendent of the Water Company at Cohasset, Mass. The paper was discussed by Mr. Robert S. Weston, Mr. Hugh McLean, and Mr. W. S. Johnson. The paper was accompanied by stereopticon pictures showing various features of the Cohasset Water Works and also views of the town.

The second paper of the afternoon was entitled "The Greenfield Water Works," and was read by Mr. George F. Merrill, superintendent of the Greenfield Water Works. This paper also was accompanied by a considerable number of interesting views.

The topical discussion (continued from the November meeting) was on the general subject of "Service Pipes, — methods used; methods of making connection at main; depth of laying; troubles from freezing; methods of thawing, etc." The following-named gentlemen participated in the discussion: R. C. P. Coggeshall, George Cassell, Allen W. Cuddeback, D. A. Heffernan, Robert J. Thomas, F. F. Forbes, I. S. Wood, Frank B. Wilkins, Robert S. Weston.

Adjourned.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Boston, Mass., Wednesday, November 11, 1914.

Present: President Frank A. McInnes, and members William F. Sullivan, Samuel E. Killam, Richard K. Hale, Lewis M. Bancroft, George A. King, and Willard Kent.

Active: Bernard F. Rogers, foreman Public Works Department, Boston, Mass.; William T. Lenehan, foreman Water Service, Public Works Department, Boston, Mass.; S. Nishioeda, Tokio Municipal Office, Water Works Department, Tokio, Japan; Estus H. Magoon, assistant professor of hydraulic and sanitary engineering, Massachusetts Institute of Technology, Boston, Mass.; Ernest B. Black, consulting engineer, Kansas City, Mo.; Walter H. McMahon, superintendent water works, Chelmsford, Mass.; Elmer G. Manahan, division engineer, Department of Water Supply, New York, N. Y.; Thomas E. Lally, assistant engineer, Public Works Department, Water Service, Roslindale, Mass.; George A. Stowers, superintendent water works, Billerica, Mass.; William F. Clark, superintendent water works, Winchendon, Mass.; Frederic H. Fay, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; Edward F. Hughes, water commissioner, Watertown, Mass.; Frederick L. Waldmyer, water registrar, Winchester, Mass.; Raymond J. Andrus, general manager Northwest Electric and Water Works, Montesano, Wash.; M. Cashman, 63½ Water Street, Newburyport, Mass.; Sturgis H. Thorndike, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; Charles M. Spofford, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; James Fitzgerald, superintendent water works, West Acton, Mass.; A. H. Grindle, superintendent Bar Harbor Water Company, Bar Harbor, Me.; George O. Adams, chemist, State Department of Health, Experiment Station, Lawrence, Mass. — 20.

Associates: *The American City*, New York, N. Y.; Power Equipment Company, Boston, Mass.; H. F. Jenks Co., Inc., Pawtucket, R. I. — 3.

Twenty applicants for Active and three for Associate membership were, by vote, recommended therefor.

One (1) applicant for reinstatement was, by vote, reinstated, and one applicant for active membership was, by vote, rejected as ineligible therefor under the Constitution of the Association.

Adjourned.

Attest: WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Boston, Mass., Wednesday, December 9, 1914.

Present: President Frank A. McInnes, and members William F. Sullivan, Robert J. Thomas, Samuel E. Killam, Richard K. Hale, Lewis M. Bancroft, George A. King, and Willard Kent.

Active: J. Harold Remick, superintendent water works and municipal light plant, Littleton, Mass.; C. W. Whiting, consulting engineer, 33 Broad St., Boston, Mass.; Eugene Carpenter, Newton, Mass.; Moses L. Brown, commissioner of public works, Quincy, Mass.; Leon Edward Dix, associate professor of civil engineering, Norwich University, Northfield, Vt.; Isaac Osgood, engineer, Boston Board of Fire Underwriters, 36 Osgood St., Andover, Mass.; Henry W. Taylor, hydraulic and sanitary engineer, 100 State St., Albany, N. Y.; William A. Tripp, engineer Tisbury Water Works, Vineyard Haven, Mass.; H. E. Crowell, superintendent water works, Haverhill, Mass.; George F. Ashton, city engineer, Salem, Mass.; Walter N. Charles, civil engineer, 176 Clinton St., New Bedford, Mass.; Roland F. Kay, meter inspector, Milford Water Works, Milford, Mass.; M. W. Carroll, water commissioner, Millers Falls, Mass.; S. F. Ferguson, 100 William St., New York, N. Y.; Oliver E. Williams, vice-president Tiffin, Ohio, Water Works, 67 Milk St., Boston, Mass.; John G. Whitman, superintendent water works, 104 Penn St., Quincy, Mass.; Philip Burgess, 8 East Long St., Room 826, Columbus, Ohio; and R. C. Harris, Department Water Works, Toronto, Ontario. — 18.

Eighteen applicants for membership were received, and the applicants were by unanimous vote recommended therefor.

Three (3) applicants were reinstated to membership, they having complied with the requirements of the Constitution.

Voted: That the annual meeting, January 13, 1915, be Ladies' Day, and that the President and Secretary be a committee to arrange therefor.

Adjourned.

Attest: WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Saturday, December 26, at 2 o'clock P.M., pursuant to call of the President.

Present: President Frank A. McInnes, and members Leonard Metcalf, Carleton E. Davis, Robert J. Thomas, Samuel E. Killam, Lewis M. Bancroft, and Willard Kent.

A communication from Mr. E. B. Rosa, Secretary Joint National Committee on Electrolysis, inviting the Association to membership in that organization, was presented and, on motion of Mr. Metcalf, seconded by Mr. Thomas, it was voted that it was inadvisable for this Association to take active official participation in their work at this time.

A report of the committee on last annual convention was presented and accepted, and President Frank A. McInnes, Messrs. Charles W. Sherman, and Frank A. Barbour were made a committee to consider the question of the manner of raising funds for future conventions.

On motion of Mr. Thomas it was voted to hold the next annual convention at the White Mountains.

Adjourned.

Attest: WILLARD KENT, *Secretary.*